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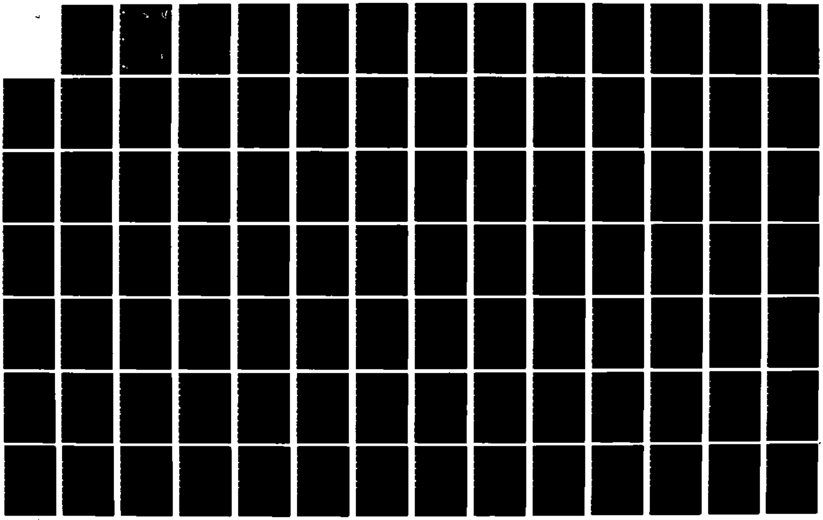

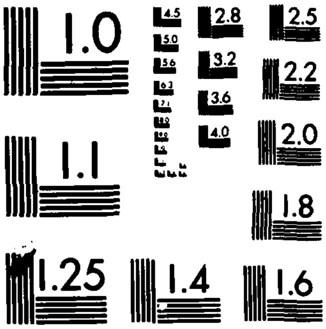

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PSC
A PROGRAMMABLE SOFTWARE CONTROLLER FOR A
MULTIPLE BLADDER SEQUENTIALLY INFLATABLE
G-SUIT

THESIS

Jerry L Marcu
1st Lt USAF

AFIT/GE/EE/83D-41

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (ATC)
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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A PROGRAMMABLE SOFTWARE CONTROLLER FOR A MULTIPLE BLADDER SEQUENTIALLY INFLATABLE G-SUIT

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Jerry L. Marcu, B.S.

1st Lt USAF

Graduate Electrical Engineering

December 1983

Preface

Today, more than ever before, the g-tolerance of human beings is of great concern to the U.S. Air Force. Present-day aircraft are designed to withstand g-stress beyond the limits of human endurance. The purpose of such aircraft is to maintain air superiority over the enemy. It is necessary to increase human g-tolerance to match that of the modern day aircraft.

The way to increase g-tolerance is to improve blood circulation in the head and eyes during periods of high +Gz-stress. The idea of applying pressure to the legs and abdomen sequentially, from the feet up, has been discussed by the aerospace medical community. However, the idea has not been thoroughly researched or tested. It is my sincere desire to provide aerospace medicine with a tool for performing that research.

This research concerns itself with developing a programmable valve actuation controller generic to g-suits of varying bladder configurations. With this controller, others may investigate sequential inflation to determine its merit.

I greatfully acknowledge the support of MSgt Gregg Bathgate, TSgt Steve Bolia, TSgt Ken Riggs, and SSgt Mike Swisher of AFAMRL for their work with g-suit fabrication and electronics in setting up the experiments. I also thank Mr. Robert Van Patten and Capt Tom Jennings for their enthusiasm, guidance, and support throughout the project, and, Dr. George Potor for his help with the Z-100 Microcomputer.

I extend my appreciation to the thesis committee for their guidance and suggestions; to Dr. Constantine Houpis and Lt Col Harold Carter for their help regarding the structuring of the research and the writing; and to Lt Col Charles Hatsell and Dr. Matthew Kabrisky for several insightful discussions and moral support.

I would also like to thank my wife, Angie, and our two boys, Peter, and Andrew, for their tolerance and understanding throughout the quest of a Masters degree.

Jerry L. Marcu

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Abstract

A bang-bang closed-loop digital programmable controller was developed for a multiple-bladder sequentially inflatable g-suit. Programmable parameters included the number of bladders, sequence of inflation, PSI/G relationship, and a g-suit refresh cycle. The software was developed in BASIC-80. Two bladders were analyzed and their transfer functions approximated (assuming linearity) for both inflation and deflation. A theoretical versus actual time response comparison revealed the degree of linearity of bladder inflation and deflation.

I. Introduction

Background

In air-to-air combat, the pilot that is able to make the tighter turns has a decided advantage over his opponent. Tight turns imply high +Gz stress on the aircraft and aircrew (Van Patten and Jennings, 1982:1). The term "+Gz stress" refers to the stress experienced due to gravitational forces (G's) acting in a negative direction along the aircraft's Z-axis (vertically downward for an aircraft at rest).

In early aircraft, airframe tolerances limited the maximum allowable +Gz stress. Later improvements led to aircraft capable of flying in conditions beyond human tolerance. Today, aircraft are built capable of withstanding nine G's sustained, and over six G per second acceleration (F-16, for example). The technology exists to build a 12g aircraft (Van Patten, 1982:1). The major limiting factor in the development of high-g aircraft is man's inability to tolerate g-stress.

From a physiological standpoint, the main problem caused by excessive +Gz force relates to blood circulation in the head, specifically the eyes and brain. Under +Gz stress, the blood is forced out of the head toward the feet. The lack of blood in the head decreases peripheral vision leading to blackout and can result in Loss Of Consciousness (LOC). The eyes and brain are, in effect, suffocating without ample oxygen. To improve human g-tolerance, the blood must be forced up out of the legs and into the head during periods of high +Gz stress (Van Patten and Jennings, 1982:3).

Improvements in human g-tolerance have not kept pace with improvements in aircraft g-tolerance. The use of certain physical maneuvers (M-1 and L-1) and constricting devices improves human g-tolerance, but not enough for the new high-g aircraft. The standard g-suit is the most practical device used for g-protection to date. It contains a five compartment air bladder that, when inflated, tightens the g-suit material around the pilot's legs and abdomen. The suit is worn like pants and the bladder inflates through the abdominal compartment, through the thigh compartment, to the calf compartments. The improved tolerance afforded by the g-suit falls short of that required for the F-16 and other high-g aircraft.

The g-tolerance of present and future aircraft increases as new materials and design philosophies evolve. If the aircraft capabilities are to be exploited, the g-tolerance of the pilot must equal or exceed that of the aircraft. This thesis looks at an alternate application of the g-suit, one that separates the bladder compartments into five separate bladders and inflates them sequentially.

Problem Statement

The problem is to develop a closed-loop, bang-bang control system, and more specifically, a computer program capable of controlling the actuation of valves used to inflate and deflate each of the individual bladders in a multiple bladder g-suit.

Discussion

This attempt to improve human g-tolerance uses a modified g-suit. Each bladder is isolated from the other four and, theoretically, each has a dedicated air supply valve, dump valve, and inlet/outlet hose.

Thus, instead of filling all the bladders through the abdominal bladder, each bladder inflates separately. For this development, hardware availability limited the number of complete bladder combinations to two.

The computer program must be flexible enough to allow the user to select any sequence of bladder inflation for a suit with any number of bladders, as well as the point at which each bladder begins inflating and stops inflating.

G-Tolerance Improvements to Date

Present g-tolerance methods include tilt-back seats, M-1 and L-1 maneuvers, Positive Pressure Breathing (PPB), the standard G-suit, and the capstan-type g-suit. Appendix B lists each of these along with selected readings if more information is desired. Use of any of the aforementioned methods results in some g-tolerance improvement, usually between 0.5 and 1.5 g's. This level of improvement sufficed until aircraft tolerance levels exceeded those of humans. As stronger airframes are developed, the desire to fly faster, higher, and with greater maneuverability grows.

More recently, g-tolerance research looked at improving the standard g-suit function. The spring-mass valve used to inflate the suit was modified to increase the flow volume (HF - High Flow) and maintain slight pressure in the bladders to decrease the volume of air needed for complete pressurization (RP - Ready Pressure). The result is the High Flow Ready Pressure Valve (HFRP). This valve has proven reliable and decreases inflation time, but only provides a one-g tolerance improvement. Nevertheless, it will soon be retrofitted into all F-15 aircraft.

The current anti-g valve actuates at 2.2g. Moog, Inc., has proposed a servo-controlled rapid response anti-g valve which lowers the "turn-on" threshold to 1.5g. In centrifuge tests at the Naval Air Development Center (NADC), the rapid response feature provided 0.5g improvement on relaxed subjects, and 1.3g improvement on subjects performing the M-1 maneuver.

The following table summarizes the g-tolerance and g-improvement due to various techniques and devices.

	G-Tolerance	G-Improvement
Relaxed Subject	3.1g	--
M-1 Maneuver	4.3g	1.2g
M-1 and g-suit	6.0g	2.9g
M-1 and Moog Valve	7.3g	4.2g

(Crosbie, 1982:7)

The standard g-valve is a product of World War II. Attempts to modify the valve serve only to improve an outdated piece of equipment and , generally, yield only slight improvements. Such attempts also tend to ignore many of the technological advances of the electronic age. The Moog, Inc. approach, that of a completely new design, is a step in the right direction. While many concern themselves with the g-valve, another school of thought focuses on the g-suit itself.

In addition to the standard g-suit, there are two other g-suit types of note. One, the capstan suit, uses the standard suit principle of material constricting the limbs and torso, but it functions by inflating tubes that run along the arms, legs, and abdomen. Another suit, the reticulated foam suit, is concerned with applying even pressure over various parts of the body (this suit is still in the development stage at this writing).

A relatively new approach, the one this thesis addresses, is more concerned with the location and timing of the pressure application than the method of application. The idea of sequential pressure application from the lower extremeties toward the head warrants investigation. Although the idea of sequentially inflating a g-suit has been discussed, no conclusive investigation has proven or disproven its possible merit. If the idea has merit, any number of suit types and methods of application can be developed to employ sequential inflation.

Therefore, the purpose of this work is to design a control system consisting of hardware and software which implements sequential g-suit pressurization. This definition is oriented primarily toward experimentation rather than operational implementation. As part of the research reported here, a computer program is designed and implemented which is flexible enough to apply to a wide variety of g-suit configurations. With this tool, the aerospace medical community can test various modes of pressure application and, hopefully, develop a g-protection philosophy capable of providing g-tolerance compatible with the F-15, F-16, and other high-g aircraft.

Scope

When this research began, information about bladder inflation was limited to characteristics of the entire suit, rather than individual inflation times and pressures. A bladder inflation test provides inflation profiles for each of the standard g-suit bladders at various supply pressures. The data provides valuable insight into the working of the leg-bladder and abdomen-bladder combination.

The program, created as part of this research, capitalizes on the knowledge of bladder response characteristics at hand, and is designed to operate a two-bladder suit but remain generic to suits with any number of bladders. The user may program any number of bladders, the inflation sequence, the G-to-bladder pressure profile, and each bladder's "turn-on" point.

Figure I-1 represents a closed-loop sampled data control system in which the computer controls the g-suit inflation. The computer compares the desired pressure with the actual bladder pressure to decide the commanded future state of each bladder according to the parameters selected by the user. The computer signals the supply and dump valves for each bladder accordingly. Hence, this is a bang-bang or on-off type control system. The software includes a very user friendly orientation help section and a parameter input program that assumes no computer expertise on the part of the user.

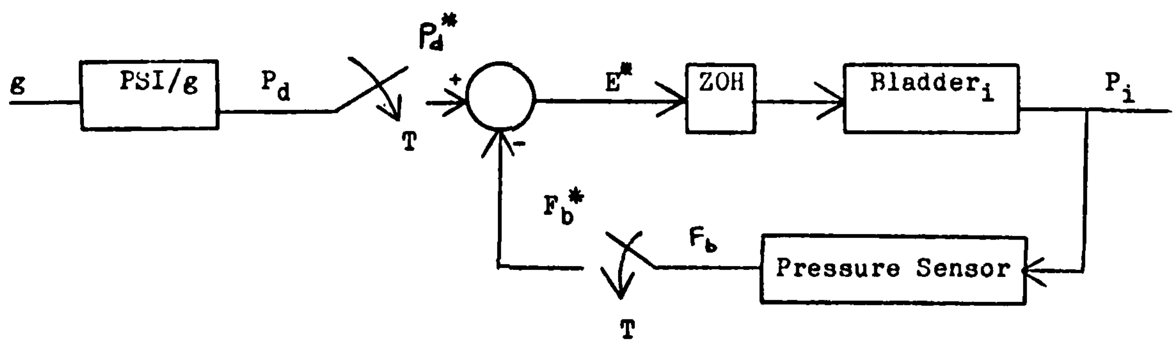


Figure I-1. Single Bladder Closed-Loop Sampled Data Control System

Approach

The idea of sequential inflation implies a suit with individual bladders. Therefore, a prototype suit is fabricated by separating the bladder compartments of the standard g-suit. Each bladder has an air inlet hose and a provision for a pressure transducer. The bladders remain in the suit fabric and the suit is tested on a mannequin at various supply pressures. The results are recorded on a strip chart.

Using the sponsor's requirements and the data from the bladder inflation experiment, the software requirements are formulated and the code is developed to operate a multiple bladder g-suit.

The computer and the g-suit bladders are interfaced, and the two-bladder system is tested and analyzed. The software is also tested on a multiple bladder simulation to verify the logic.

Presentation

This thesis is presented in essentially chronological order. Each chapter represents a phase in the basically empirical approach to developing a workable software g-suit controller.

Chapter II presents the overall system requirements, describes the system design as the combination of several subsystems, and identifies the requirements of each subsystem.

Chapter III describes the bladder inflation experiment and interprets the results.

Chapter IV states the software requirements and explains the software design.

Chapter V presents a qualitative overview of the two bladder system and a quantitative analysis of experimental versus theoretical bladder characteristics. The theoretical characteristics are obtained by developing the bladder transfer functions for both inflation and deflation of the two bladders, and obtaining the time response to a step input using a computer simulation.

Chapter VI draws conclusions and suggests ideas for further system development and improvement.

Appendix A contains the software listing for the g-suit controller.

Appendix B lists additional readings about g-protection methods.

Appendix C provides a list of equipment used in the bladder experiment of Chapter III.

Appendix D contains the tabular listing of times and pressures for the theoretical and experimental inflation and deflation profiles. It also exhibits the graphical approach used to determine the transfer function time constants of Chapter V.

Appendix E is the User's Guide and Appendix F is the Data Dictionary.

II. Development of Specifications and Additional Requirements

Many of the system requirements and specifications are mentioned and discussed in Chapter I. The purpose of this chapter is to formally state, in an orderly fashion, the system requirements. Specifically, this chapter presents the sponsor's requirements and explains the design of the system that is the vehicle for the development of the software controller. Please note, the focus of analysis and design in this thesis is on the software controller subsystem. The requirements for this subsystem appear in Chapter IV.

The Air Force Aerospace Medical Research Laboratory (AFAMRL) at Wright-Patterson Air Force Base is the sponsor of this thesis. As stated in the Introduction, the purpose of this project is to provide AFAMRL with a tool for testing the concept of sequential inflation for improved g-protection. The following requirements statements describe the sponsor's desired objectives in proposing this project.

Requirements and Specifications

1. A multiple bladder g-suit shall employ a bang-bang digital control system to control the actuation of solenoid air valves. These on-off type valves are used to fill and dump the bladders.

The system should control the valves using a digital signal (on/off, 1/0, HI/LO). It should accept the analog bladder pressure signals, represent them in 8-bit format, and adjust them using a calibration factor.

2. The system should be capable of controlling up to 25 bladders.

NOTE: Due to hardware limitations, this thesis demonstrates and evaluates a two bladder *g*-suit controller. The software, however, can support more than two bladders and is limited by the available memory and the computational time delay.

3. The system must operate in real time. That is, the system must be capable of controlling a real *g*-suit under test conditions such as centrifuge testing.

4. The system should respond to changes in g as fast as possible. The response of the two bladder suit should be evaluated. In particular:

- Response is considered "fast enough" if the system is sensitive to g changes as small as 0.25g when the PSI/G profile has a slope of 1.5 PSI/G.

- Response time must be minimized. Although a specific response time is not stated, the response time should be an improvement over that of the current g-suit (g-level of actuation - 2.2g, g-suit inflation time - 0 to 10 PSI in 4.6 seconds) (Burton, Shaffstall, Jaggers, 1980).

5. The system must be programmable. The programmer should be able to enter the specific characteristics of the g-suit into the program, as well as the way the suit is to respond to changes in g.

6. The system must be capable of maintaining the desired pressure in the bladders using the programmed design criteria and the sampled pressure fed back from the bladders.

7. The system should include a provision for a refresh cycle. This

secondary inflation scheme should perform a repumping function during periods of sustained g-stress. Prolonged exposure to constant g stress results in venous pooling in the legs. It is possible that repumping the legs will solve the pooling problem. The refresh cycle should be fully programmable.

System Design

The system described in the following paragraphs is designed to demonstrate the two bladder system required for this thesis as well as the generic software controller. Figure II-1 shows the various subsystems that comprise the two bladder system.

Keep in mind that, while this section is called "System Design", the main design is in the software subsystem. The design presented here is more of an assemblage of the necessary hardware to allow the microcomputer to "talk" to the fill-dump valves.

The system consists of seven subsystems. They are:

1. Z-100 Microcomputer
2. Software Controller
3. Cromemco D/7A S-100 Bus Conversion Board
4. Computer/Valve Interface
5. Valve Pair/ Hose/ Bladder
6. Air Supply
7. Transducer/Amplifier

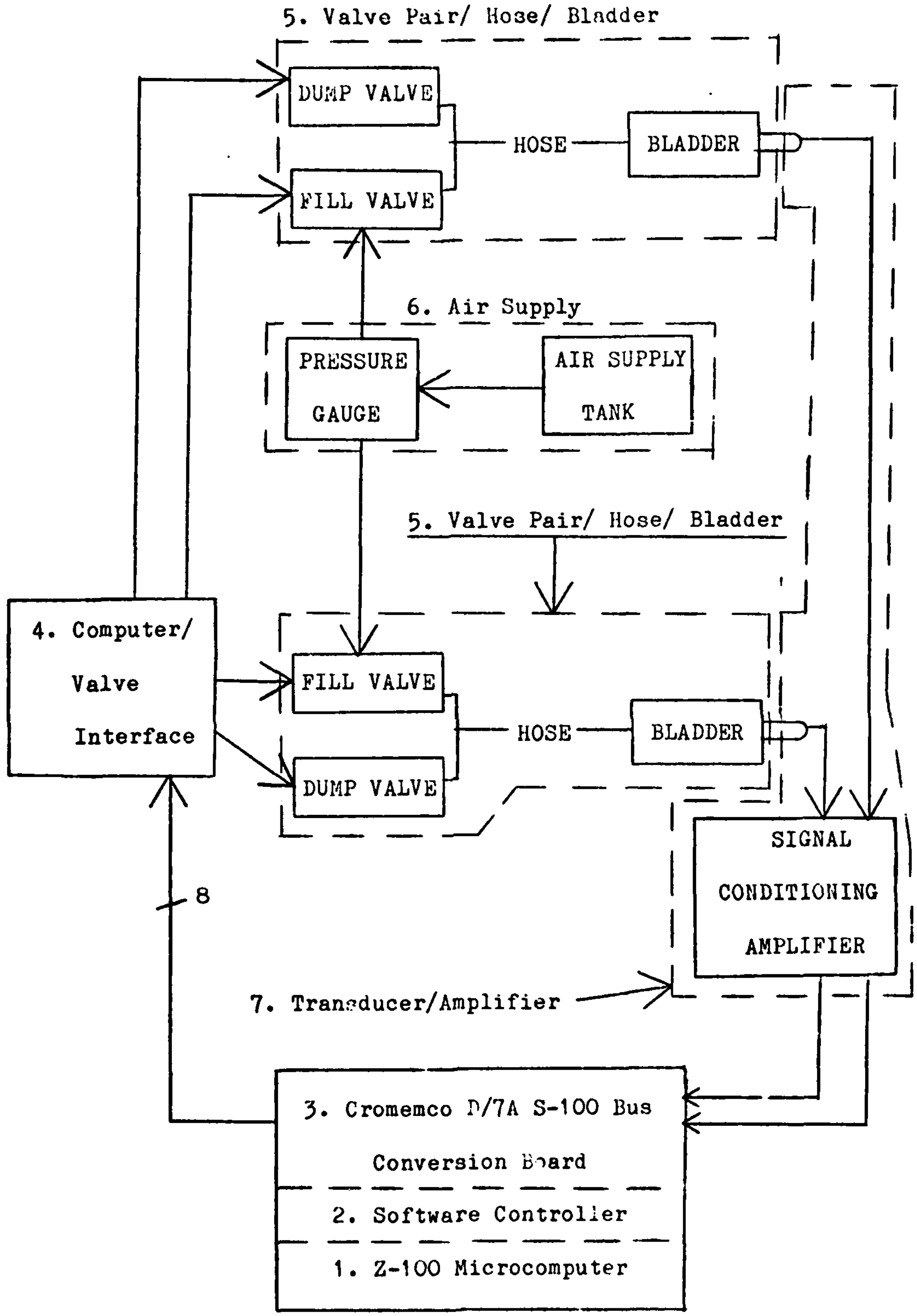


Figure II-1. Two Bladder System (Block Diagram)

Subsystem 1 - Z-100 Microcomputer. The sponsor furnished the Z-100 Micromputer for the software development and the hardware portion of the digital controller. It is a 5 MHz machine with both 8- and 16-bit capability. More important, it is an S-100 Bus machine which makes A/D conversion a plug-in operation. The Z-100 has 128K bytes of RAM making it a powerful supporter of large memory program applications. The particular Z-100 used has a 10 Mbyte hard disk and a DSDD 5 1/4 floppy disk drive.

In summary, the Z-100 is a powerful base from which to develop the software controller subsystem and control the suit inflation.

Subsystem 2 - Software Controller. The software controller includes the user input program to allow the user to "design" the g-suit in software, the control program to operate the system according to the desired specifications, and the G-input program to allow the user to input the desired g value via the computer keyboard. A diagram of the software controller is shown in Figure II-2.

CONTROL PROGRAM
G-INPUT PROGRAM
USER INPUT PROGRAM

Figure II-2. Software Controller Components

Chapter IV, Software Design, details the working elements of the software controller subsystem. As stated earlier, the true analysis and design portion of this thesis involves the design of the software controller. For now, let it suffice to say that the software controller is developed in BASIC-80 using an interpreter and is utilized in compiled form for speed of response. Even in compiled form, the software computation time is the major limitation because software execution delays the sampling time.

Subsystem 3 - Cromemco D/7A S-100 Bus Conversion Board. The A/D conversion of the pressure feedback signals is accomplished by the D/7A Board. The board has one 8-bit parallel digital input/output channel and seven channels of analog input/output. For this design, the valve actuation signals are sent over the 8-bit parallel digital output channel as an 8-bit word. Actually, only the first nybble is used as bits 0-3 actuate fill valve 1, dump valve 1, fill valve 2, and dump valve 2, respectively.

The pressure transducers in Subsystem 8 feed back pressure information through two of the seven A/D channels via the signal conditioning amplifiers.

The maximum capability of the system is seven pressure feedback signals and eight digital on/off signals. Actually, the 8-bit digital output word can be encoded to represent up to 256 sets of valve instructions, but the idea of assigning a single bit to a single valve is much more straightforward.

To increase system capability, additional boards may be plugged into the remaining S-100 Bus slots of the Z-100. For instance, three

D/7A Boards can support 21 bladder feedback signals and 24 valve actuation signals. Also, other S-100 Bus boards are readily available with more channels than the D/7A. In summary, the subsystem capability exceeds the necessary requirements for a two bladder system.

Subsystem 4 - Computer/Valve Interface. The computer/valve interface involves the retrofit of an existing system developed by AFAMRL for an experiment of no concern here. Thus, the details of the interface design are not presented here. The subsystem is a box with pushpanels and lights. It was originally used in some reaction experiments with monkeys. The box contains switching logic and relays to accept an 8-bit word and, based on that word, turn various lights on or off. For use in this experiment, the valves replace the lights, thus, the relays turn the valves on and off based on the word sent from the Z-100. The hardware details of the box are not part of this thesis and the interface is treated as a black box in this system.

Subsystem 5 - Valve Pair/ Hose/ Bladder. The objects of control are the fill/dump valves paired for each bladder. In this design, one valve performs the filling function and the other performs the dumping function. Future designs may be able to combine the functions in a single valve.

The valves are MAC Solenoid Valves with one-half inch ports. The entire air passage from source to bladder is one-half inch to allow a large capacity airflow and provide rapid filling. The valves actuate electronically in approximately 11.0 milliseconds and are powered by a minimum of 25.0 PSI bias pressure. This rapid actuation prevents the valve function from contributing substantially to delays in response.

The hose has a 200 PSI work pressure rating so it may be considered rigid over the 0 to 10 PSI range of the bladders.

The bladders are actual g-suit bladders which have been separated into individual units. In the current g-suit, the bladders are all interconnected so they inflate together. By separating them, the g-suit has distinct bladders, each with a dedicated valve-hose-transducer combination.

Subsystem 6 - Air Supply. The air supply is furnished by a compressed air tank. One pressure gauge meters the valve bias pressure to at least 25.0 PSI. A second gauge meters the bladder supply air. The compressed air tank is sufficient to provide well over the necessary bias pressure and allow the bladder supply pressure to be varied as desired.

Subsystem 7 - Transducer/Amplifier. The pressure transducers are Endevco 8506-50 miniature transducers. They are linear to within three percent over the working range of 0 to 50 PSI. The 8506-50's are strain gauge type pressure sensors. In addition, a Statham pressure transducer is used as a backup in the event of an Endevco transducer failure. The Endevco's are very fragile but desirable for this work because they are very small.

The amplifier used is an existing physiological amplifier supplied by AFAMRL. The transducer voltage output is amplified to match the input specification of the D/7A board. This allows the computer to see the pressure range of 0 to 10 PSI as a numerical range from approximately 0 to 120. Thus, the computer may detect pressure changes as low as 0.0834 PSI. Like the interface, the amplifier is considered a black box in this thesis.

Summary

This chapter formally states the sponsor's requirements for this research and explains the system design used to develop the software controller. The next chapter examines the result of a bladder inflation experiment performed to provide insight into the characteristics of a single bladder inflation. This knowledge, along with the sponsor's requirements, leads into the design of the software controller.

III. Bladder Inflation Experiment

The first step in developing a software controlled g-suit involves the analysis of bladder response characteristics. Until now, g-suit research has been concerned with the response of the entire five compartment bladder rather than isolated bladders. Thus, the experimental data analyzed in this chapter provides the much needed insight for development of the software requirements. The hardware and experimental layout are described in Appendix C.

Equipment

The Modified G-Suit. For this test, the standard g-suit bladder has been separated into five distinct bladders: two calf, two thigh, and one abdominal. Each bladder is tested separately. The bladders remain inside the g-suit fabric, and each is provisioned for a pressure transducer.

The Bladders. The standard g-suit comes in many sizes. For a given size, there are three sizes of bladders. The two calf bladders are identical and opposite, as are the two thigh bladders. The calf bladders are the smallest, the thigh bladders larger, and the abdominal is largest. The bladder fabric is expandable, hence, the bladder inflates much like a very stiff balloon. This experiment uses a large suit because it best fits the mannequin used in some of the tests.

Inlet Air Hose. Each bladder has an inlet air hose cut to length to simulate an F-16 configuration. The hose lengths for each bladder are shown in the following table:

Bladder	Hose Length
Left Calf	60 inches
Right Calf	52 inches
Left Thigh	44 inches
Right Thigh	36 inches
Abdomen	28 inches

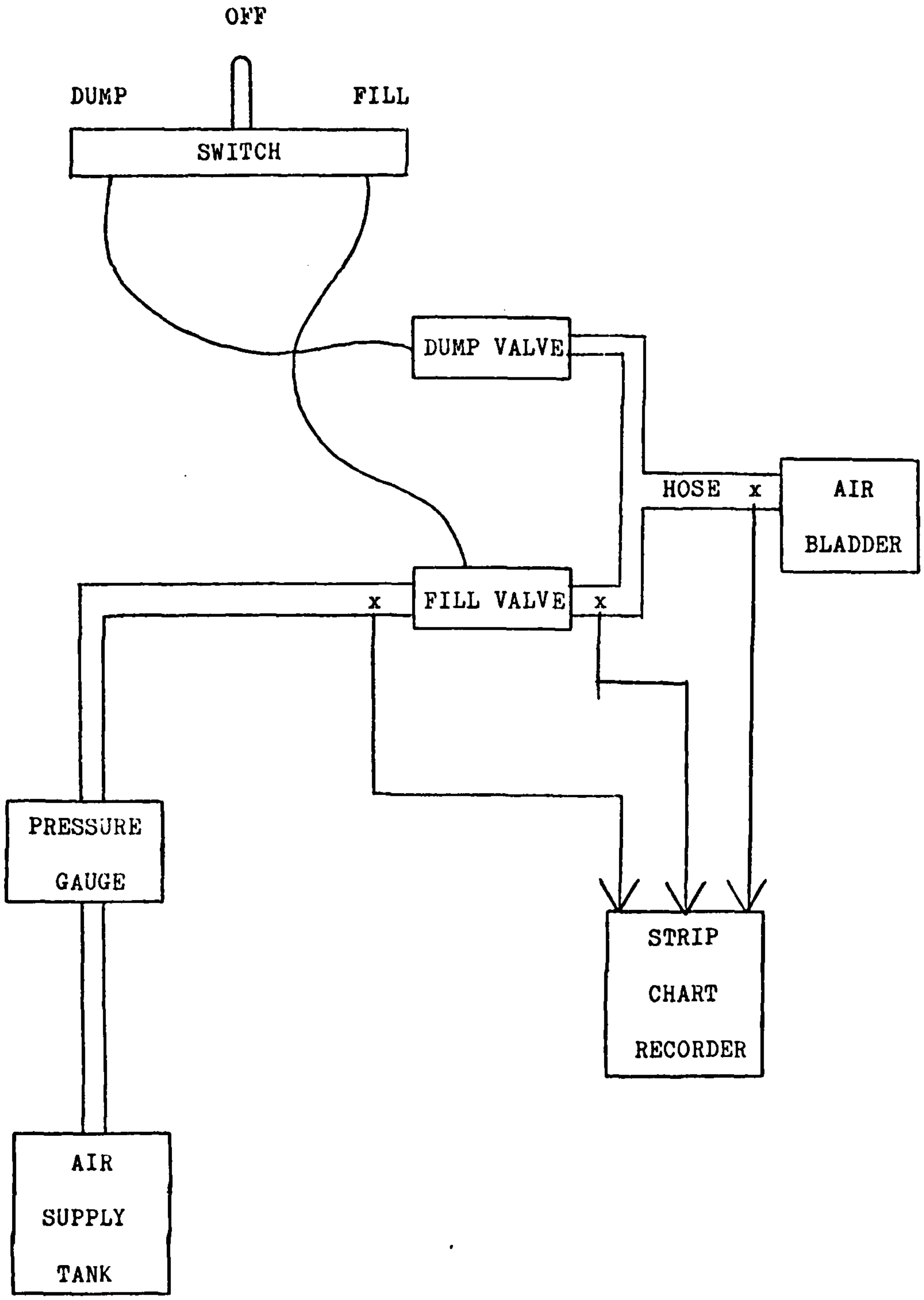
The inlet air comes to the suit from the right side, so, the left leg bladders need longer hoses than the right leg bladders. Actually, the hose lengths and valve locations deserve closer scrutiny, but for this work they are selected as described. Once a working system is developed, the air supply and valve locations may be optimized for specific operating conditions.

The Valves. For inflation and deflation, industrial soleniod pilot valves provide filling and dumping via a manually thrown three-position switch.

Procedure

Figure III-1 shows the block diagram of the test set-up. To test a bladder, the bladder's inlet air hose is connected to the fill/dump valves and a transducer is installed into the bladder fixture. The supply pressure is set manually with a pressure gauge. Each bladder is tested at 5, 10, 15, and 30 PSI supply pressure with the results recorded on a strip chart. Pressure transducers monitor the pressure at the valve as well as in the bladder. This is used to illustrate the effect hose length has on bladder inflation.

To inflate a bladder, the switch is thrown to the "FILL" position.



x - PRESSURE TRANSDUCER LOCATIONS

Figure III-1. Bladder Inflation Experimental Layout (Block Diagram)

To dump, it is thrown to the "DUMP position. To hold, the switch is placed in the "OFF" position.

Important Parameters

Inflation Time. The time response of a bladder to a step input has no overshoot (explained in Chapter V). Thus, at low supply pressures, that is, supply pressures lower than the maximum allowable bladder pressure, the inflation time may be thought of as the rise time. By increasing the supply pressure, the inflation time is decreased and the inflation profile is linearized.

Pressures over 10 or 11 PSI create a situation where the air supply must be cut off before the bladder pressure reaches that of the supply. Therefore, discussion of inflation time is based on rise time for supply pressures of 10 PSI or less, and cutoff, or final time for pressures over 10 PSI.

Deflation Time. The deflation time is the time spent venting the bladder to atmosphere. In some cases, deflation dumps from the current pressure to zero, while, in others, from current pressure to a desired final pressure.

Long Term Expansion Drop(LTED). LTED refers to the decrease in bladder pressure due to bladder fabric expansion after valve cutoff. The bladder pressure does not settle for many seconds, or even minutes, because of the fabric expansion. The expansion results in a change in the pressure distribution across the bladder's inside surface. The changing shape and size of the bladder results in a non-constant surface area enclosing a constant capacity of air. Hence, the LTED is that change in pressure due to bladder surface area changes during periods of constant capacity.

Short Term Pressure Drop (STPD). STPD refers to the rapid drop in pressure that occurs immediately after the air supply is cut off. When the fill valve is closed, the inertia of the airflow into the hose creates a low pressure area at the valve end of the line. The hose/bladder combination settles quickly, but the result is a premature pressure reading in the bladder that is higher than the pressure after the STPD ends.

Bladder Volume. Bladder volume, although important, is not a parameter of concern to this thesis. It is discussed here for completeness. Although relationships exist between bladder volume and inflation time, pressure drop, and supply pressure, volume is not a useful parameter by itself because of phenomena like bladder fabric expansion and STPD.

An anti-g system produces its effect by applying pressure to the body. Every human being is different, so, every leg-bladder and abdomen-bladder combination is different. Therefore, to apply the same pressure to different subjects may require different air capacities. Hence, pressure, not volume, is the parameter of concern.

In reality, the bladder volume includes the inlet air hose volume. The hose lengths for this configuration tend to decrease the differences in bladder volumes because the smaller bladders have longer hoses. To determine the effect hose length has on inflation, the two calf bladders may be compared, as may the two thigh bladders, because they are identical bladders with different hose lengths. The hose volumes for each bladder in the modified g-suit are listed in the following table:

Bladder	Hose Volume
Left Calf	11.78 inches^3
Right Calf	10.21 inches^3
Left Thigh	8.64 inches^3
Right Thigh	7.07 inches^3
Abdomen	5.50 inches^3

Hose length and size are parameters that may be optimized in a final system design where the operation conditions are established. For now, the object is to determine if the length affects the response.

Data Interpretation

The data interpretation is divided into two parts: one part for the response to 5 and 10 PSI step inputs, and another for the response to 15 and 30 PSI supply pressures.

Part One: Low Pressure Analysis - Response to 5 and 10 PSI Step Inputs.

The data from the response to step input portion of the experiment is presented in Table III-1. The actual values in Table III-1 are not as important as their relaionship to one another and their general magnitude. The following paragraphs discuss some of the important relationships and bladder characteristics exposed in the experiment.

Table III-1. Bladder Response to Step Input

5 and 10 PSI Supply Pressure

Bladder	Supply Pressure	Rise Time	Deflation Time	LTED
	PSI	seconds	seconds	PSI/second
Left	5.4	1.3	0.20	0.022
Calf	9.8	0.72	0.16	0.039
Right	5.4	1.3	0.20	0.010
Calf	9.7	0.70	0.16	0.088
Left	5.4	3.2	0.30	0.033
Thigh	9.7	1.50	0.48	0.066
Right	5.3	3.4	0.30	0.024
Thigh	9.7	1.54	0.48	0.072
Abdomen	5.3	4.8	1.60	0.026
	9.7	3.32	3.12	0.052

Rise Time. In general, the rise time decreases as the supply pressure increases. Increasing the supply from 5 to 10 PSI decreases the rise time by fifty percent for the thigh and calf bladders. As expected, the rise time is less for the calf bladders than the thigh bladders because the calf bladders are much smaller. Likewise, the abdominal bladder rise time is the largest. It seems that the idea of a g-suit with bladders of uniform size may have merit. Perhaps a set of small bladders inflating in parallel could replace the large bladders, thus, decreasing inflation time. This concept allows for optimization of bladder size and supply pressure.

The different hose lengths have no noticeable effects on the inflation time. Their effects may be neglected unless drastic differences in hose length are present, or hose volumes become so large that their capacity begins to rival that of the bladders. For this test, a comparison of the calf bladders shows no difference in inflation time. Likewise for the thigh bladders. Thus, effects due to differences in hose lengths may be neglected for this thesis.

The inflation profile is nearly linear over the range of the rise time for the 10 PSI supply pressure profile, but not for the 5 PSI pressure profile. At 5 and 10 PSI supply pressure, the bladders spend approximately seven percent of the total inflation time initially reaching ten percent inflation. They spend about fifty percent of the total inflation time inflating from ninety to one hundred percent inflation. Both of these supply pressures are too low to rapidly inflate large bladders, but the 10 PSI supply pressure may be desirable for the smaller bladders.

Deflation Time. The deflation time depends on the bladder size and the initial pressure. The small calf bladders deflate in about 0.2 seconds at 5 PSI and 0.16 seconds at 10 PSI. The thigh and abdominal bladders take longer to deflate as the initial deflation pressure increases. Thus, the deflation time of the small bladders is affected more by the initial pressure while the deflation time of the large bladders is affected more by the total volume of air that must expiate. Thoeretically, there may be a bladder size that has a constant deflation time regardless of the initial pressure. This bladder must be slightly larger than the calf bladder but much smaller than the thigh bladder.

Figure III-2 illustrates this concept by plotting the theoretical curves representing the pressure at the time deflation begins, and comparing the bladder size to the deflation time.

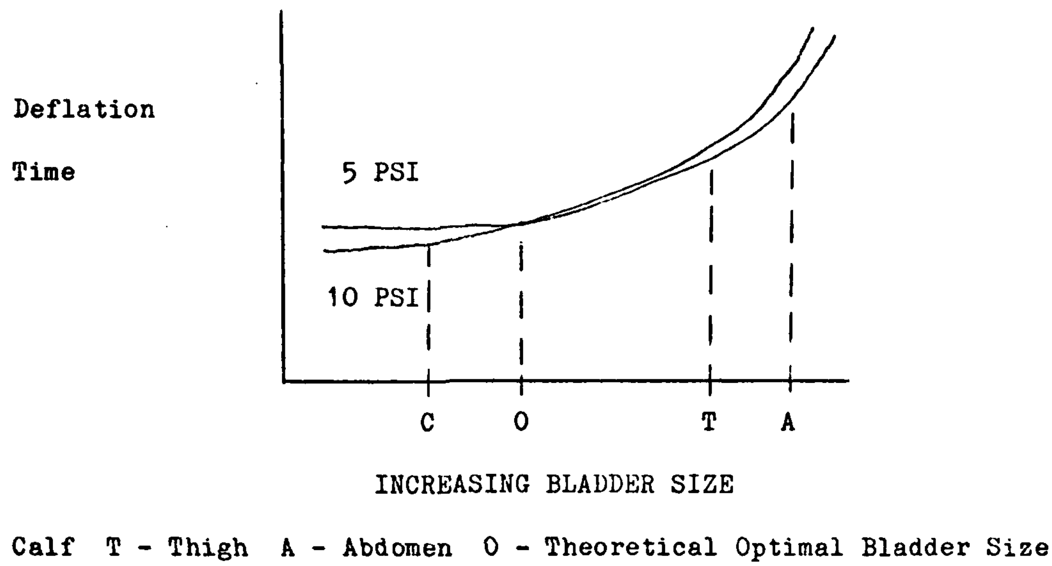


Figure III-2. Bladder Size Optimization Based on Deflation Time (not to scale)

From Figure III-2 it is noted that, for small bladders, the deflation time is relatively independent of size, but, as the bladder size increases, the deflation time becomes more and more dependent on size. Also, as the bladders become larger, higher initial pressures cause faster deflation. It is this phenomenon that points to an optimal bladder size that has a constant deflation time regardless of the initial pressure. If this is true, another variable of the system may be eliminated. Please note, Figure III-2 is only the illustration of a concept and not the plotting of actual data.

Another way to control deflation is to provide passive resistance to venting by decreasing the valve port size. This provides some backpressure and slows the deflation. The only reason to increase the deflation time is to give the controller time to sense the pressure as it drops and stop the deflation if desired. However, the main concern of this research is the inflation of the suit, so, deflation by venting to atmosphere is sufficient.

LTED. The pressure drop due to fabric expansion is slight, but must be considered. It becomes more of a factor as the system becomes more sensitive to changes in g. For instance, if the system is required to maintain the pressure precise to 1.0 PSI, the effect of expansion drop is minimal. As the desired pressure "window" decreases, fabric expansion causes the pressure to drop below the desired value much sooner.

To illustrate, the sponsor's requirement is that the system be sensitive to g-changes of 0.25 PSI at a PSI/G slope of 1.5. Thus, the system must be able to change the pressure by as little as 0.375 PSI. This becomes increasingly difficult as the supply pressure is increased and the number of bladders is increased. For example, the thigh takes 1.5 seconds to inflate from 0.9 PSI to 8.8 PSI at a 9.7 PSI supply pressure. The slope of the inflation profile is

$$(8.8 - 0.9 \text{ PSI})/(1.5 \text{ seconds}) = 5.367 \text{ PSI/second}.$$

To increase the bladder pressure by an additional 0.375 PSI requires

$$(0.375 \text{ PSI})/(5.367 \text{ PSI/second}) = 0.0712 \text{ seconds}.$$

In other words, the valve must remain open for 0.0712 seconds to increase the bladder pressure by 0.375 PSI. This may not be enough time for the system to perform all its computations, monitor the other bladders, and return to close the fill valve.

Consider the delay introduced by the time required to close the solenoid valves used in this experiment. The valve actuation time is 0.011 seconds, and its delay allows the pressure to increase an additional

$$(0.011 \text{ seconds})(5.367 \text{ PSI/second}) = 0.059 \text{ PSI}.$$

Thus, the valve closure time contributes a pressure error of

$$(0.059 \text{ PSI})/(0.375 \text{ PSI}) = .157$$

or, 15.7 percent. Other delays occur due to computational time and the time needed to input a new g-value. The g input time is 55 microseconds using the Cromemco D/7A board, so, its contribution is less than 0.1 percent, certainly negligible when considered by itself. The computational delay naturally depends on the specific code used, so, its contribution cannot be quantified here. Let it suffice to say that the computational time may present as much, or more, delay than the actuation time.

Remember, the system is trying to hit a pressure window. Depending on when the g-value is input, the system may or may not be able to activate valve shut-off in time to prevent the pressure from increasing past the desired point. In this case the systems natural pressure drops have a positive effect regarding the system's attempt to achieve a desired pressure. Consider the following scenario:

> The system senses a pressure above the desired pressure and activates valve shut-off. By the time the system gets around to checking the bladder pressure again, the systems natural pressure drops have had time to decrease the pressure.

Depending on the actual pressure at the time of valve closure, the pressure drop may or may not be enough to prevent the next sample from falling above the desired window. Indeed, the pressure drop may be too much, and the bladder pressure may drop below the desired window. This may lead to a "hunting" situation as depicted in Figure III-3.

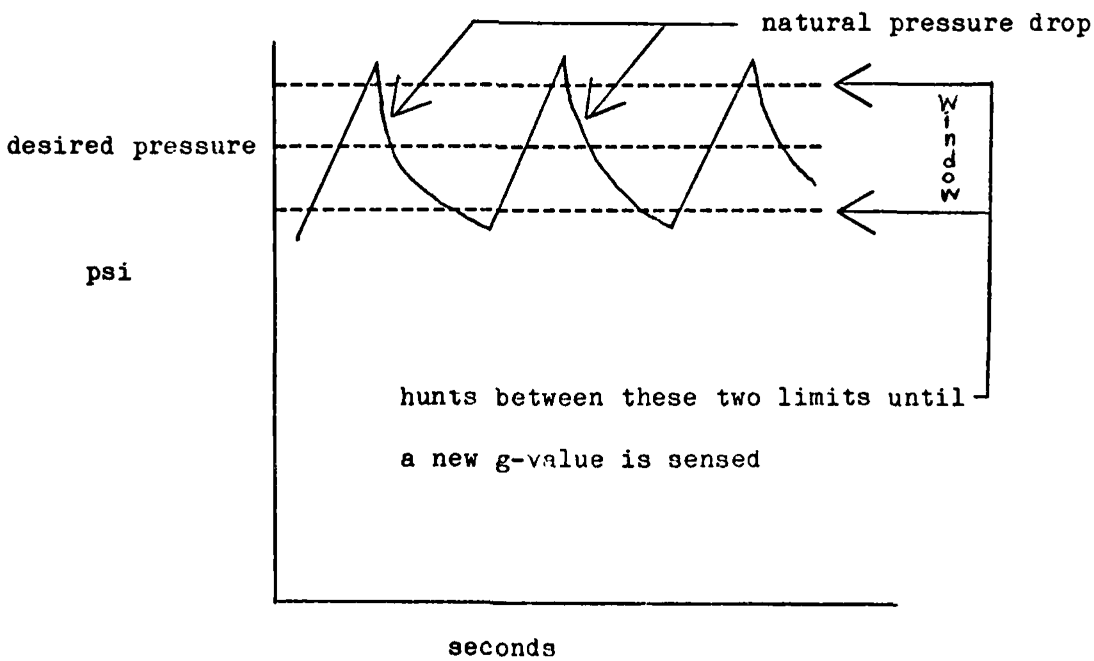


Figure III-3. Hunting Situation Caused by Natural Pressure Drop

Both conditions are undesirable and their occurrence indicates that either the g-sensitivity is too small, the supply pressure is too high, and/or the computational time is too long.

The factors affecting the phenomenon discussed above may be considered as variables of the system, and are as follows:

1. Bladder size
2. Supply pressure
3. Pressure widow size
4. Slope of the inflation profile
5. Sample time
6. LTED
7. STPD
8. Location of sensed pressure within the window

It is not feasable to attempt a theoretical evaluation of the system's ability to achieve a desired pressure at this point with the idea of developing a general theory for all cases. There are simply too many variables in the system. Each time a system is developed, its characteristics may be determined experimentally. This is done for the two bladder system presented in Chapter II, with the results presented in Chapter V.

To summarize, the effects of LTED can only be evaluated on a system by system basis and not generalized for all systems. A new evaluation is required when any change to the system or operational conditions is made.

STPD. Short term pressure drop does not exist when responding to a step input and allowing full inflation before valve cutoff. This is due to the bladder pressure equaling that of the source at cutoff, thus, the airflow into the bladder has no inertia to create the low pressure area at the valve end that causes STPD. In the high supply pressure situation, STPD does present a problem. It is discussed in the high pressure analysis later in this chapter.

Summary - Low Pressure Analysis

The following statements summarize the important information gleaned from the low pressure experiment.

1. The right and left calf bladders respond the same in spite of an eight inch difference in hose length (likewise for the thigh bladders).

2. Higher supply pressures provide decreased inflation times.

3. Higher supply pressures increase the minimum possible pressure change.

4. The inflation profiles are nonlinear, however, the rise time profile for the 10 PSI supply pressure is nearly linear.

5. STPD is of no concern at low supply pressures.

6. LTED has an effect on the minimum possible pressure change. It must be evaluated for each design and each set of conditions.

Part Two: High Pressure Analysis - Response to 15 and 30 PSI Supply

It is determined in the low pressure analysis that the hose length does not affect performance in this application. Thus, for the high pressure test, it is assumed that the hose length has no effect. The high pressure test is performed only on the right calf and thigh bladders and the abdominal bladder.

Inflation Time and Inflation Profile. Increasing the supply pressure yields two important improvements to system response. One, inflation time decreases, and two, the PSI/second profile approaches linearity. Table III-2 presents the inflation rates and inflation times for the calf, thigh, and abdominal bladders at 15 and 30 PSI supply pressure. The inflation rate is an average which is determined from several experimental pressure increase profiles. The range the slopes is presented an discussed later in this section (see Table III-3).

Table III-2. Bladder Response to 15 and 30 PSI Supply Pressure

Bladder	Supply Pressure	Final Pressure	Inflation Time	Inflation Rate
	PSI	PSI	seconds	PSI/second
Calf	15	10.8	0.56	19.3
	30	10.0	0.32	31.3
Thigh	15	10.6	1.16	9.1
	30	10.7	0.88	12.2
Abdomen	15	10.8	2.24	4.8
	30	10.6	1.58	6.7

At high pressures, the fill valve is closed manually before the pressure in the bladder reaches that of the supply to prevent bladder explosions. For this work, the maximum bladder pressure is considered to be 10 PSI although a few more PSI are tolerable. Through trial and error, the final pressures shown in Table III-2 are achieved by opening the valve at zero bladder pressure and closing the valve at the desired pressure.

Notice that the calf bladder inflates in 0.32 seconds at 30 PSI supply pressure, much faster than the 5 and 10 PSI times. Even the thigh bladder inflates in less than one second. The abdominal bladder is still fairly slow at about 1.5 seconds.

The inflation profiles at 30 PSI supply pressure are very linear so the slopes (PSI/second) in Table III-2 are truly that. At 15 PSI the slopes are approximations, but the 15 PSI profile is nearly linear above 0.2 PSI. Figure III-4 illustrates the difference in the two profiles.

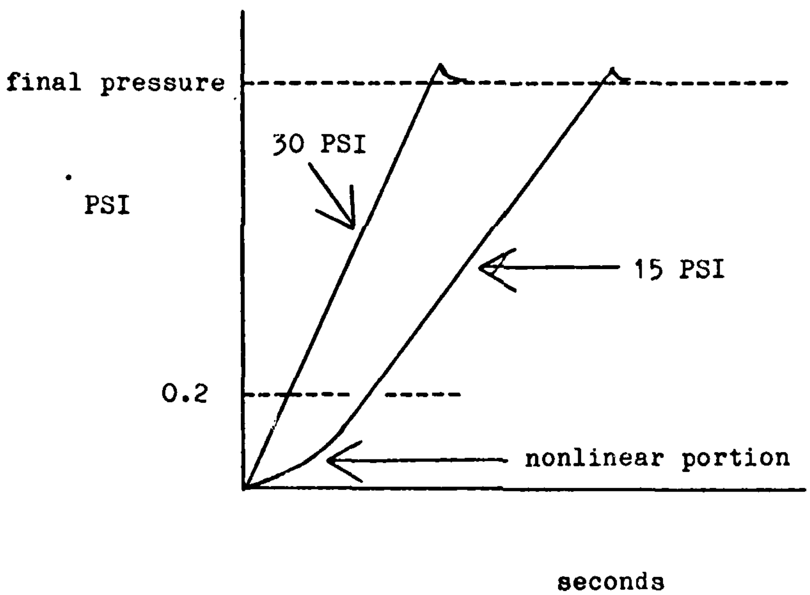


Figure III-4. Comparison of Inflation Profiles at 15 and 30 PSI Supply (not to scale)

Over several trials, the slopes for the calf bladders at 30 PSI range from 30.0 to 36.7. These slopes are generated by inflating from an initial pressure other than zero, say P_i, to a final pressure, say P_f. This demonstrates predictable bladder response to the application of high pressure air. Table III-3 lists the ranges of the slopes for all three bladders at 30 PSI supply pressure.

Table III-3. Range of Slopes for Three Bladders at 30 PSI Supply

Calf	30.0 to 36.7 PSI/second
Thigh	12.2 to 13.4 PSI/second
Abdomen	6.0 to 9.2 PSI/second

The main reason for a given bladder to vary in slope is due to error in reading the strip chart. Many of the inflations lasted only 0.1 seconds. It is difficult to discern 0.1 from 0.09 or 0.11 so a 10 to 20 percent error is possible. Nevertheless, the slopes may be said to be reproducible and constant over the working pressure of the bladders (0.20 to 10.0 PSI).

From the standpoint of speed and linearity, the 30 PSI supply is the most desirable of the four pressures tested. Further increases in supply pressure increase linearity and decrease inflation time, but 30 PSI supply pressure provides inflation that is probably too fast for the small calf bladders, so, there is no need to go higher at this time.

The limit on supply pressure is different for each application. A given system reaches a point where the valve cannot open and close fast enough to increase the pressure by the desired amount. In other words, a relationship exists between the magnitude of the difference between P_i and P_f (the window discussed in the low pressure analysis), the supply pressure, and the bladder size. Assuming that bladder sizes vary, The supply pressure may be adjusted to yield any inflation profile slope desired. This concept turns a multiple bladder suit into a "virtually" uniform bladder size suit, as long as each bladder has a provision for a gauged supply pressure.

STPD. At high supply pressures, LTED remains tolerable, but there is a problem with STPD. The profile shown in Figure III-5 illustrates the concept of STPD.

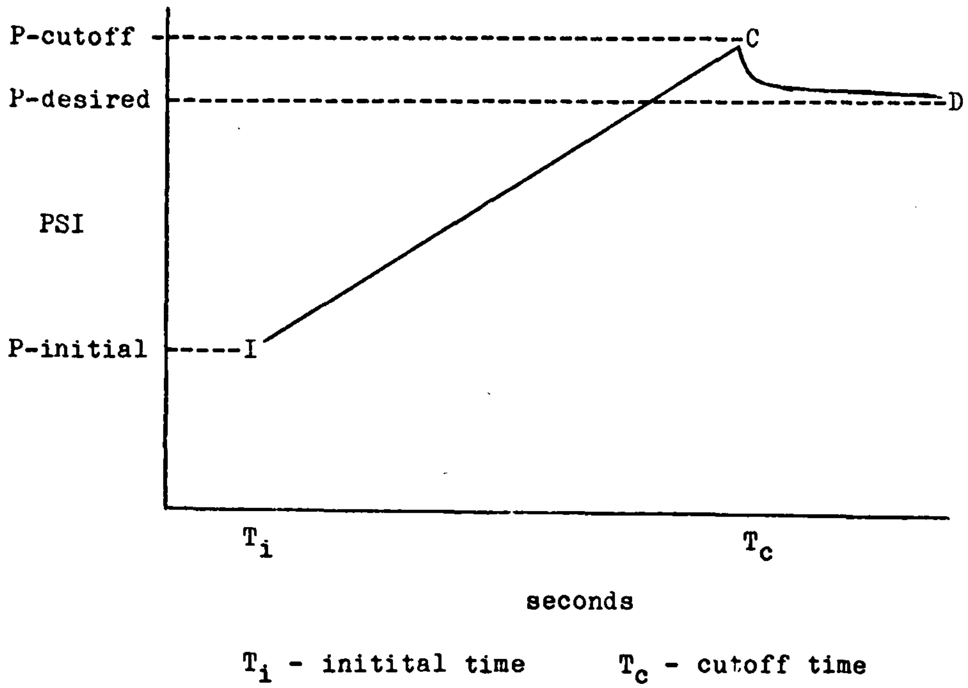


Figure III-5. Illustration of STPD (not to scale)

The point "I" represents the state of the bladder at the beginning of inflation. The point "C" is the point at which the valve cuts off. The point "D" locates the point of transition from unacceptable to acceptable pressure drop.

For the sake of discussion, assume that a STPD of -0.2 PSI/second is acceptable. Then, to achieve a desired pressure, the bladder must inflate to the cutoff pressure, some value greater than the desired pressure. In other words, the system must intentionally overinflate the bladder.

The STPD is different for each bladder-supply pressure combination. Table III-4 presents the experimental results of the STPD for the three bladders tested at 30 PSI supply pressure.

Table III-4. STPD at 30 PSI Supply Pressure

Bladder	Number of Samples Taken	Mean Pressure Drop
Calf	7	0.68
Thigh	6	0.62
Abdomen	11	0.37

Table III-4 reveals the relative magnitude of the STPD for the three bladders and suggests a nonliear inverse relationship between bladder size and pressure drop. Pressure drop seems to be more of a problem in small bladders. This is because a small bladder's air capacity is less than that of large bladders, thus, the low pressure area created at the valve end of the hose has a bigger impact on the small bladder's pressure.

A further investigation of the data quantifies the time expired and the pressure drop incurred due to STPD before achieving a -0.2 PSI/second slope. Table III-5 shows the results.

The figures indicate a STPD with order of magnitude one(1). It appears that the STPD may present a problem when the software controller tries to reach and hold a desired pressure. As with LTED, the system's natural pressure drops and inherent delays affect the system's ability to hold the pressure within the desired window. The selection of a supply pressure indicates which type of pressure drop affects the system more. Ideally, each bladder can have a dedicated air supply which can supply it with air at the desired pressure. This is not possible for this design, but should be considered for future g-suit designs.

Summary - High Pressure Analysis

The following statements summarize the important information gleaned from the high supply pressure experiment

1. A 30 PSI supply pressure provides a linear inflation profile and decreased inflation times for the three bladders tested.

2. A bladder responds predictably to the application of high pressure air over any time period, that is, in going from P_i to P_f, the slope of the inflation profile is constant.

3. LTED is tolerable if the effects of STPD are compensated.

4. The STPD is of order of (1 PSI/second).

Conclusions Drawn From the Bladder Inflation Experiment Regarding the Development of Software Controller Requirements

Many ideas have been presented in this chapter regarding bladder inflation and the design of future g-suits. Some are directly involved in this thesis, some are informational. The focus of this thesis is on the software controller design. The following statements summarize the bladder inflation concepts that affect the requirements of such a controller.

1. The factors affecting a bladder's inflation characteristics are

bladder size and bladder pressure.

2. An inflated bladder cannot hold a constant pressure because of STPD and LTED. STPD is the more destructive of the two, dropping the pressure at a rate approaching 1.0 PSI/second for the first second after cutoff.

3. The higher the supply pressure, the closer to linearity is the inflation profile, and the steeper its slope.

4. The minimum possible pressure change increases as the supply pressure increases.

IV. Software Design

The main thesis design objective is the Programmable Software Controller (PSC) for a sequentially inflatable, multiple bladder g-suit. This chapter presents the software design by stating the software requirements, developing the controller algorithm, diagramming the software modules, and explaining each module.

Software Requirements

The software requirements are developed from two sources: (1) the sponsor's requirements of Chapter II, and, (2) the results of the bladder inflation experiment of Chapter III. The software requirements of the PSC are as follows:

1. The programmable variables of the PSC include

   A. Number of bladders,

   B. Sequence of inflation,

   C. Desired bladder pressure to g relationship,

   D. Optional provision for refresh cycle,

   E. Calibration factor for adjusting the digitized pressure transducer inputs.

2. The program is developed in BASIC with a BASIC-80 interpreter.

3. The user input portion shall accept keyboard entries and be very user friendly.

4. The code for the realtime control portion shall be time efficient to minimize computational delay.

5. The code shall be modular to facilitate editing, revising, and

enhance understanding.

6. The code shall include a module to accept the current g value entered by the user via the keyboard.

7. The code shall permit the user to correct any misentries and revise any parameters originally entered, without starting over.

8. When dismissing the PSC, the code shall insure that all bladders are dumped before relinquishing control.

9. The code shall limit the bladder pressure to 10 PSI.

10. The code, while providing for sequential inflaion, shall permit the bladders to inflate in parallel if desired.

Algorithm Design

The PSC is really two programs combined as one. The programmable portion allows the user to construct the entire environment in software, the environment being the g-suit design, the philosophy of its inflation, and the corresponding g-to-bladder pressure relationship.

The controller portion senses the g value entered at the keyboard and brings the suit to a final state as programmed. The design of the PSC actually begins with the control portion. Once the control parameters involved are known, then the programmable portion performs the necessary calculations and executes the required control law.

Before proceeding to the algorithm development, a glance at Figure IV-1 reveals the overall PSC design, combining the programmable portion and the control portion with a decision module that allows the user to

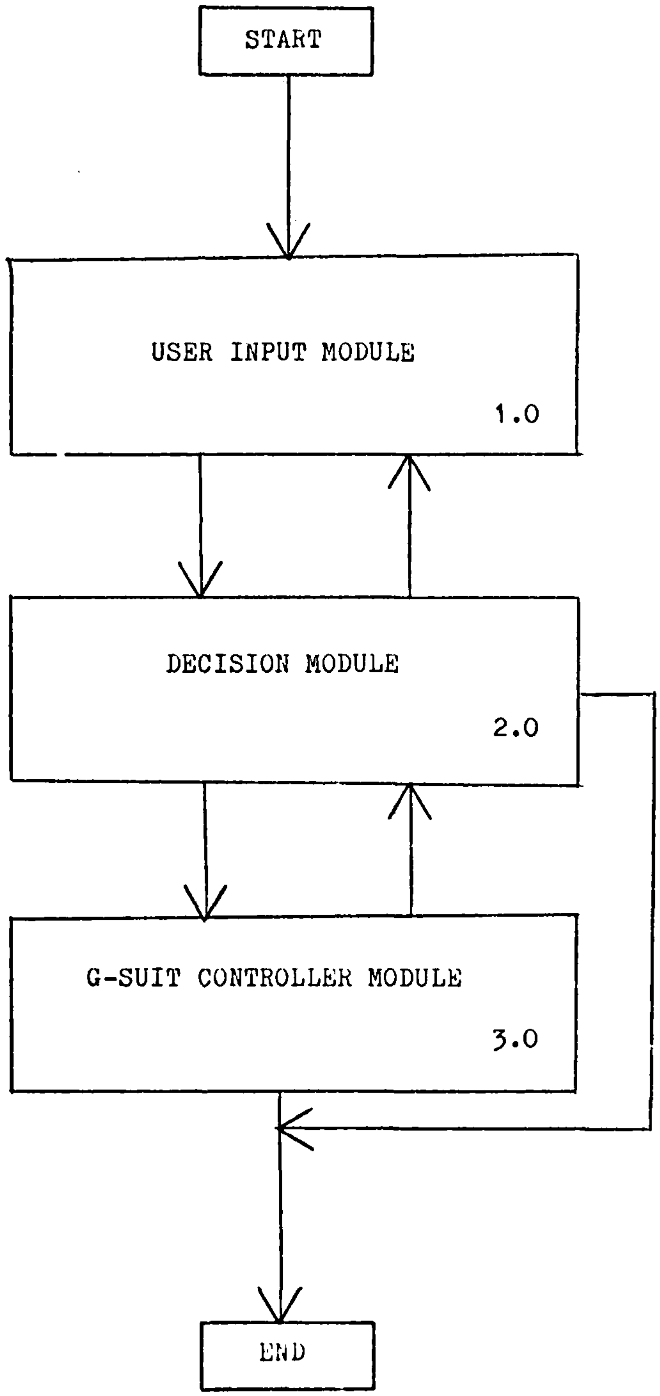


Figure IV-1. PSC - Programmable Software Controller revise the g-suit parameters as well as operate the controller.

The block numbering scheme is such that the block number indicates the path of ascension or descension of submodules. For example, the submodules of Block 1.0 may be Blocks 1.1 and 1.2, below 1.2 may be 1.2.1, and below 1.2.1 may be 1.2.1.1, 1.2.1.2, 1.2.1.3, and 1.2.1.4.

Algorithm Development of the Controller. The object of the control portion is to sense the g, use it to determine the desired state of the g-suit, and achieve that state using sequential inflation. Thus, a first cut at the algorithm is

1. Sense g,
2. Determine the desired state,
3. Achieve the desired state,
4. RETURN to Step 1.

Determination of the desired state is a function of the programmed number of bladders and the PSI/G relationship. Notice, also, that if the g value is unchanged from the previous sample, the desired state is unchanged. The algorithm becomes

1. Sample g,
2. IF g does not equal LASTG,
   THEN determine the desired pressure,
3. Achieve the desired pressure,
4. RETURN to Step 1.

A problem arises in Step 3. What if the g changes before the system reaches the desired pressure? Since the bladders are inflated using fill and dump valves, Step 3 should just compare the desired pressure to the actual pressure of each bladder, use the result to decide the state of the valves, and return to sense g again while the bladders fill, dump, or hold. Now, the algorithm is

1. Sense g,
2. IF g does not equal LASTG,
   THEN determine the desired pressure (DPSI),
3. FOR each bladder,
   3a. Sense the bladder pressure (BPSI),
   3b. IF BPSI is less than DPSI THEN fill valve on,
       ELSE IF BPSI equals DPSI THEN valves off,
           ELSE dump valve on,
4. RETURN to Step 1.

This last attempt inflates the bladders according to the PSI/G relationship, but where is the sequential inflation? Since the purpose of this system is to apply pressure to the body by increasing the bladder pressure, bladder pressure is the logical choice as the parameter on which to base sequential inflation. Bladder Number 2 should be inflated only when its pressure is below that desired, <u>AND</u>, Bladder Number 1 has reached the desired percentage of its inflation. Thus, the desired point is another programmable parameter of the PSC.

This additional <u>AND</u> condition in Step 3 makes the algorithm complete. With this approach, the PSC is capable of sequentially inflating any number of bladders according to any inflation scheme the user desires. The final algorithm, then, is

1. Sense g,

2. IF g does not equal LASTG,

   THEN determine the desired pressure (DPSI),

3. FOR each bladder,

   3a. Sense bladder pressure (BPSI),

   3b. IF BPSI is greater than DPSI THEN dump valve on,

      ELSE IF BPSI is less than DPSI AND BPSI of the previous

         bladder is greater than N% of DPSI

         THEN fill valve on

      ELSE valves off,

4. RETURN to Step 1.

Now, a bladder may only inflate when the previous bladder is over its threshold and the bladder is below the desired pressure. That point may be one hundred percent inflation, in which case the inflation shall be called sequential and consecutive. If the threshold is zero percent, the inflation can be called parallel, and between zero and one hundred percent, sequential and overlapping. Figure IV-2 diagrams the flow of the controller algorithm.

Program Structure - Programmable Portion of the PSC

The programmable portion of the PSC is very straightforward, but very long. The program prompts the user to enter the desired parameters by asking the appropriate questions. The emphasis of the design is on user friendliness. The responses are set equal to the appropriate variables.

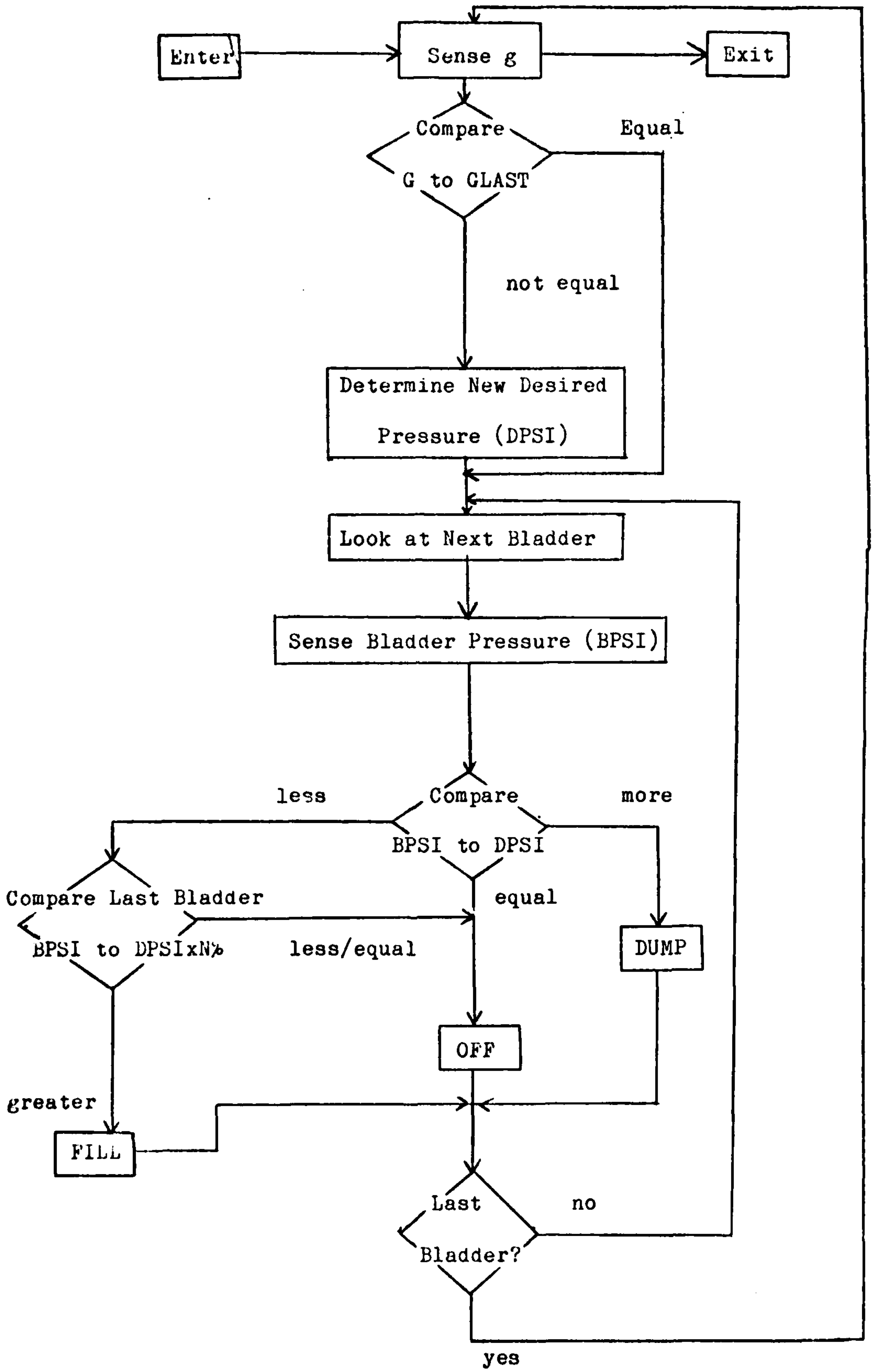


Figure IV-2. Flowchart for Block 3.0 - G-Suit Controller

Figure IV-3 illustrates the structure of the User Input Module, Block 1.0 of Figure IV-1.

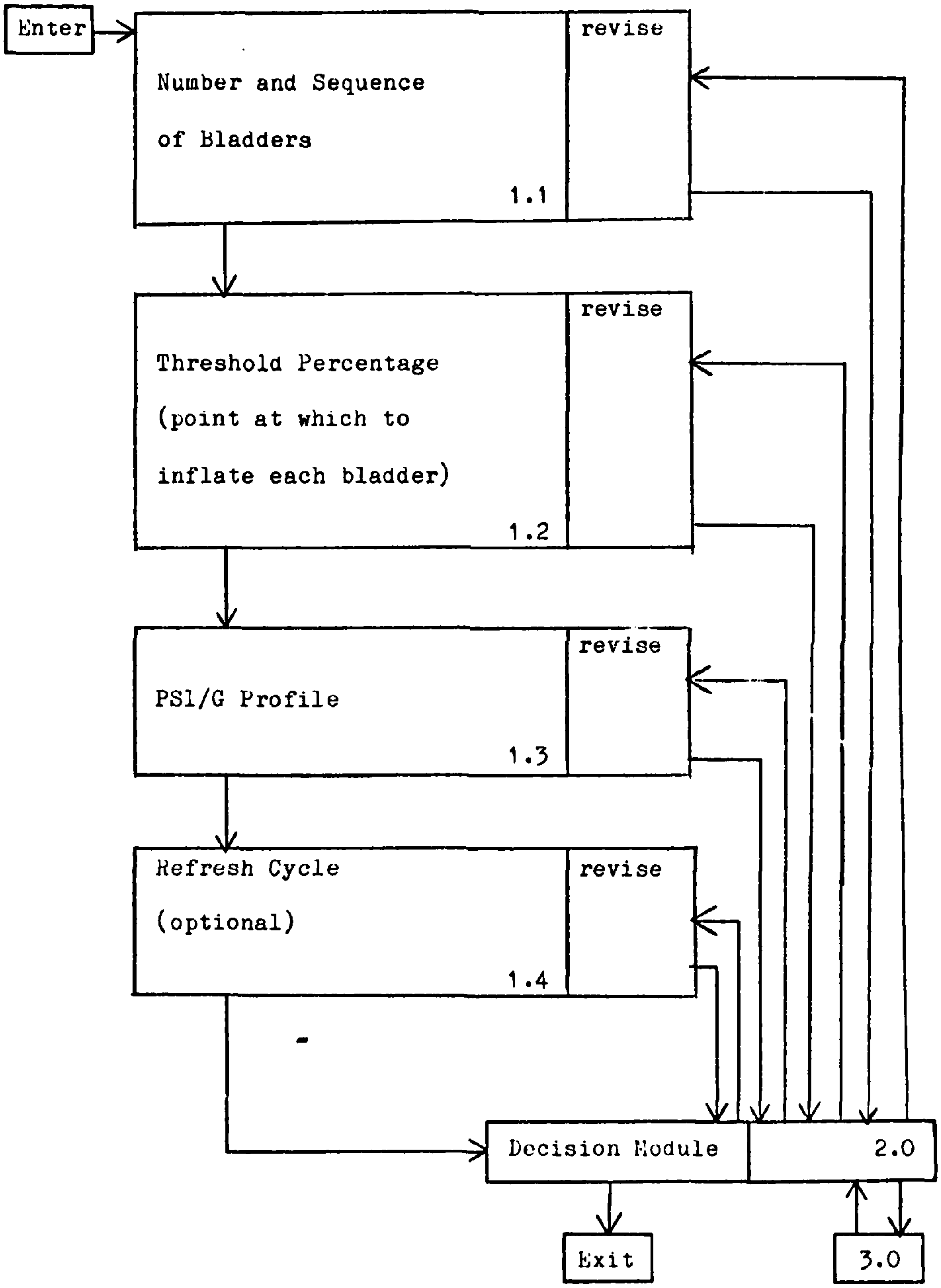


Figure IV-3. Submodules of Block 1.0 - User Input Module

The first time through the program, the user cycles through Blocks 1.1, 1.2, 1.3, and 1.4 before relinquishing control to the Decision Module, 2.0. After that, the user may choose to run the controller and inflate the g-suit, or return to any submodule of Block 1.0 for revision. In any case, the user always has the option of returning to the decision module where the PSC may be terminated.

Now the program structure is complete. Figure IV-1 shows the modular interaction of the decision module with the controller and user input modules. Figures IV-2 and IV-3 detail the controller and the user input modules further. The remainder of this chapter discusses each module, the philosophy behind it, and the variables it establishes or uses.

Modular Description

This section is divided into two parts. The first part describes each of the variables established in the user input modules of the programmable portion of the PSC. The second part explains how the variables are used by the controller portion of the PSC to operate a sequentially inflatable, multiple bladder g-suit.

Part One: User Input Modules and Submodules

Module 1.0 - User Input Module. The purpose of Module 1.0 is, initially, to call the various submodules that allow the user to enter the PSC parameters. It also provides the user with the option of obtaining a hard copy of the parameters once they are entered. The last thing it does is transfer control to the Decision Module, 2.0.

NOTE: Modules 1.1 - 1.4 obtain all their values from the keyboard.

Module 1.1 - Number and Sequence of Bladders. Module 1.1 accepts the number of bladders and sets it equal to "N". It also sets the number of bladders in each leg equal to "L". L is useful because, in most designs, the right and left legs of the g-suit are identical and opposite. For suits of this type, the PSC automatically assigns values to many of the variables making programming very quick. Setting "L" to zero allows the user to treat the bladders individually.

The bladders are numbered by position, starting with the left foot, and zig-zagging up the legs to the abdomen. For example, consider a seven bladder suit with three bladders in each leg. Figure IV-4 shows the location assigned to each bladder.

7	
ABDOMEN	
5	6
3	4
1	2
LEFT	RIGHT
FOOT	FOOT

Figure IV-4. Bladder Locations for a Seven Bladder Suit with Three Bladders in Each Leg

The sequence is established by setting the subscripted variable BLADDER(I) equal to the bladder location. For the seven bladder suit example, assume the abdominal bladder inflates first, then the left leg from the bottom up, then the right leg from the bottom up. The sequence variable, Bladder(I), has the following values:

Sequential Order I	Location BLADDER(I)
1	7
2	1
3	3
4	5
5	2
6	4
7	6

Thus, BLADDER(I)'s purpose is to step through the bladders sequentially by letting I go from 1 to N, regardless of bladder position.

Another variable, B(I), is established for the purpose of stepping through the bladder locations from 1 to N and viewing the sequence number. Thus, in the last example, B(1) equals 2, B(2) equals 5, and so on. In other words, Bladder(B(I)) equals I. This variable, B(I), is used to "talk" through the computer/valve interface via the D/7A board. For instance, the bladder in location 1 has its transducer hardwired to input port 1, bladder 2 to input port 2, and so on. If it is desired to sense the pressure in the bladder that is sequentially first, the PSC can input from Port BLADDER(1). However, if it is desired to sense the pressure in the bladder in location 1, the PSC can input from Port B(1).

Standard Inflation is a term that refers to the case where Bladder(I) equals I. The legs inflate in parallel from the bottom up followed by the inflation of the abdomen. More is said about parallel inflation in the Module 1.2 description.

Module 1.2 - Threshold Percentage (The point at which to inflate the next bladder). Now that N, L, and BLADDER(I) are known, Module 1.2 accepts percentages and sets them equal to turnon levels for each bladder. This is the basis for sequential inflation. The I-plus-first bladder begins to inflate when the I^{th} bladder reaches its turnon point. If Bladder Number 1's turnon point is fifty percent , Bladder Number 2 begins inflating when Bladder Number 1 is half pressurized. If Bladder Number 2's turnon point is thirty percent, then Bladder Number 3 begins to inflate when Bladder Number 2 is three-tenths pressurized, and so on.

Two bladders have special turnon points. They are the zeroeth and N^{th} bladders. The zeroeth bladder's turnon point is made less than zero percent so that any time the first bladder's pressure is less than that desired, it will inflate. The zeroeth bladder is imaginary. It only exists in software to start sequential inflation.

The N^{th} bladder's turnon point is made very large so that it is never reached. This is because there is never a reason to inflate the N-plus-first bladder (it does not exist).

The turnon factors are between zero and one, and are held by the variable TURNON(I), where I is the sequential position as before. Module 1.3 converts the factors to pressures using the PSI/G relationship.

Before exiting, Module 1.2 designates bladders that inflate in parallel. The variable IPARALLEL(I) holds the sequential number of the bladder that inflates parallel to Bladder I. For example, if

PARALLEL(3) equals 4, then Bladders 3 and 4 inflate in parallel. The turnon point of Bladder Number 3 is made large so it won't affect the situation. The turnon point of Bladder Number 4 detemines when Bladder Number 5 inflates.

If BLADDER(I) has no parallel bladders, IPARALLEL(I) equals zero, thus, the imaginary Bladder Number 0 is made parallel to Bladder I and no physical bladder will inflate.

Module 1.3 - PSI/G Profile. Figure IV-5 shows the three submodules of Module 1.3.

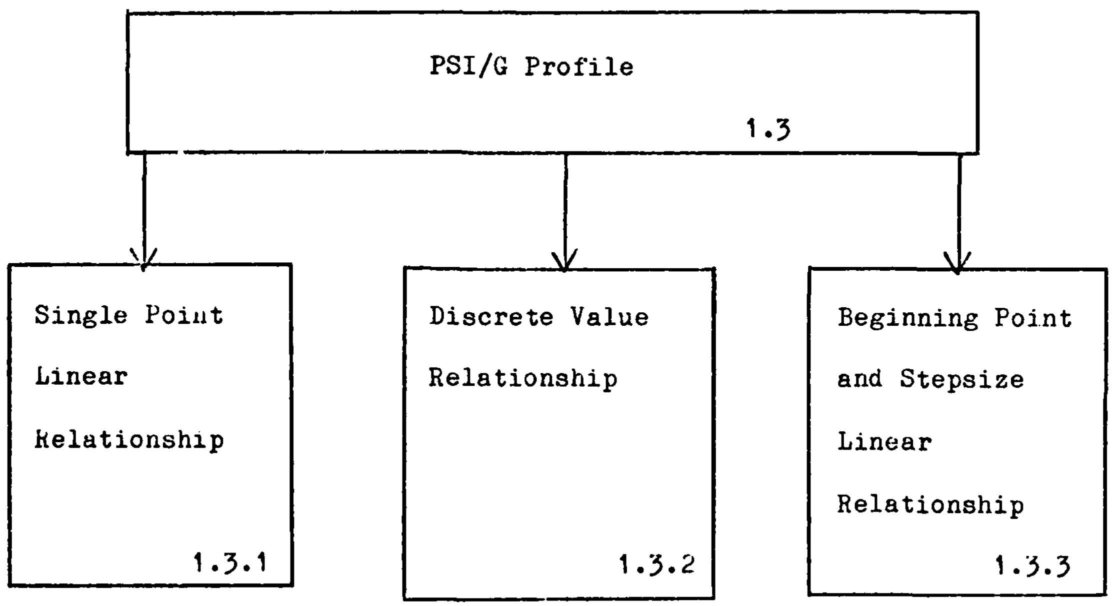


Figure IV-5. Submodules of Module 1.3 - PSI/G Profile

Module 1.3 allows the user to select one of three methods to enter the PSI/G relationship into the PSC. The minimum and maximum allowable bladder pressures are selected before entering a PSI/G submodule. The minimum pressure, PSIMIN, becomes a "ready pressure" maintained by the system during periods of little or no g-stress. The maximum pressure, PSIMAX, is a safety limitation to prevent injury and suit damage.

The purpose of the PSI/G relationship is to convert the sensed g-force into a desired bladder pressure. Because the system is digital, the PSI/G relationship must be discretized. It exists, then, as a step function, made up of a series of g-ranges that convert to desired pressures. The size of the g-range determines the system sensitivity. Figure IV-6 illustrates this concept.

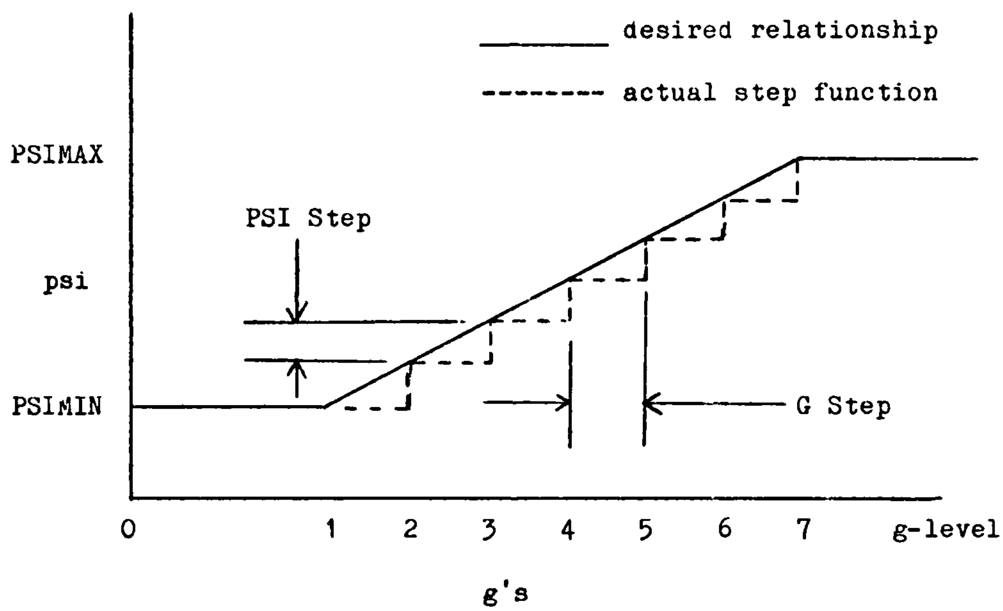


Figure IV-6. Discretized PSI/G Relationship

<u>Module 1.3.1 - Single Point Linear Relationship</u>. Module 1.3.1 forms the PSI/G relationship by accepting user inputs for the slope and one pair of pressure and g values on the desired PSI/G line. It then algebraically determines the line representing the PSI/G relationship. The ends of the line are located using the minimum and maximum pressures so that the system is bounded by the pressure limits. Then, the g

stepsize is entered, and, starting at the g value of minimum pressure, the discrete G and PSI values are determined.

Module 1.3.2 - Discrete Value Relationship. Module 1.3.2 provides a brute force method of entering the PSI/G relationship. Each pair of G and PSI values are entered directly, starting from the g of activation, and ending at the g of maximum pressure. This permits a non-constant g stepsize and allows the user to input a "nonlinear step function."

Module 1.3.3 - Beginning Point and Stepsize Linear Relationship. Module 1.3.3 accepts the beginning PSI and G values and the desired PSI and G stepsizes. It establishes the G and PSI pairs by starting at the first pair and stepping up until the maximum pressure is reached.

The result of using any one of the submodules is a set of discrete G and PSI pairs. Thus, there exists a table-look-up situation for finding a desired bladder pressure from the sensed g value.

The tables mentioned here are actually arrays in the computer's memory. For example, assume there are five bladders and ten PSI-G pairs in the PSI/G profile. There are two one-dimensional arrays for the ten discrete G values and the ten discrete PSI values. In addition, there is a two-dimensional array, 5 x 10, containing ten possible threshold pressures for each of the five bladders.

Notice that, if the g value changes before the suit can fully inflate, the desired pressure and threshold pressures also change. Thus, the PSC dynamically maintains the desired suit pressure, that is, it can "change horses in midstream."

The PSI and G variables are held by P(J) and G(J) respectively, where J is the level of the sensed g and corresponding PSI. The threshold pressures are held by THRESHOLD(I,J), where I is the bladder and J, again, is the level.

Module 1.3 - Refresh Cycle (Optional). The refresh cycle is completely separate from the normal g-suit function. It is a secondary inflation scheme invoked manually from the keyboard by striking "R". It is designed to perform a "re-"exsanguination of the legs and abdomen during periods of sustained g-stress. Of course, it may serve any purpose the user desires because it is fully programmable.

The refresh cycle consists of a set of states that the g-suit achieves one at a time. A state consists of: a Bladder Of Concern (BOC), which is the bladder being monitored for that state; a Desired Dump Pressure (DDP), which is the pressure that the BOC desires; the number of bladders that are to deflate in the current state (NUMDUMP); and the location numbers of those bladders (KDUMP). A cycle consists of a specific number of states (NUMSTATES) and the cycle is considered complete when the last state is achieved. The following example illustrates the workings of the refresh cycle.

Refresh Cycle

Number of States, NUMSTATES = 3 Number of Bladders, N = 5

Parameter	State	BOC	DDP	NUMDUMP	KDUMP
Variable	I	KBOC(I)	RPSI(I)	NUMDUMP(I)	KDUMP(I,J)
	1	2	0	2	1,2
	2	4	0	2	3,4
	3	5	0	1	5

Explanation

State 1. Two bladders (NUMDUMP(1) = 2), 1 and 2 (KDUMP(1,1) = 1, KDUMP(1,2) = 2), are deflated until Bladder 2 (KBOC(1) = 2) reaches 0 PSI (RPSI(1) = 0).

State 2. Bladders 1 and 2 begin to reinflate. Two bladders (NUMDUMP(2) = 2), 3 and 4 (KDUMP(2,1) = 3, KDUMP(2,2) = 4), are deflated until Bladder 4 (KBOC(2) = 4) reaches 0 PSI (RPSI(2) = 0).

State 3. Bladders 1 and 2 continue reinflating until they reach the desired pressure. Bladders 3 and 4 begin reinflating. One bladder (NUMDUMP(3) = 1), 5 (KDUMP(3,1) = 5), deflates until it reaches 0 PSI (RPSI(3) = 0).

End of cycle.

After reaching the last state, the refresh cycle returns control to the controller which resumes its effort to maintain the desired pressure in the bladders. During the refresh cycle, the g is not sensed, so it must be used cautiously.

Part Two - Controller Portion of the PSC

The structure of the controller software is shown in Figure IV-7.

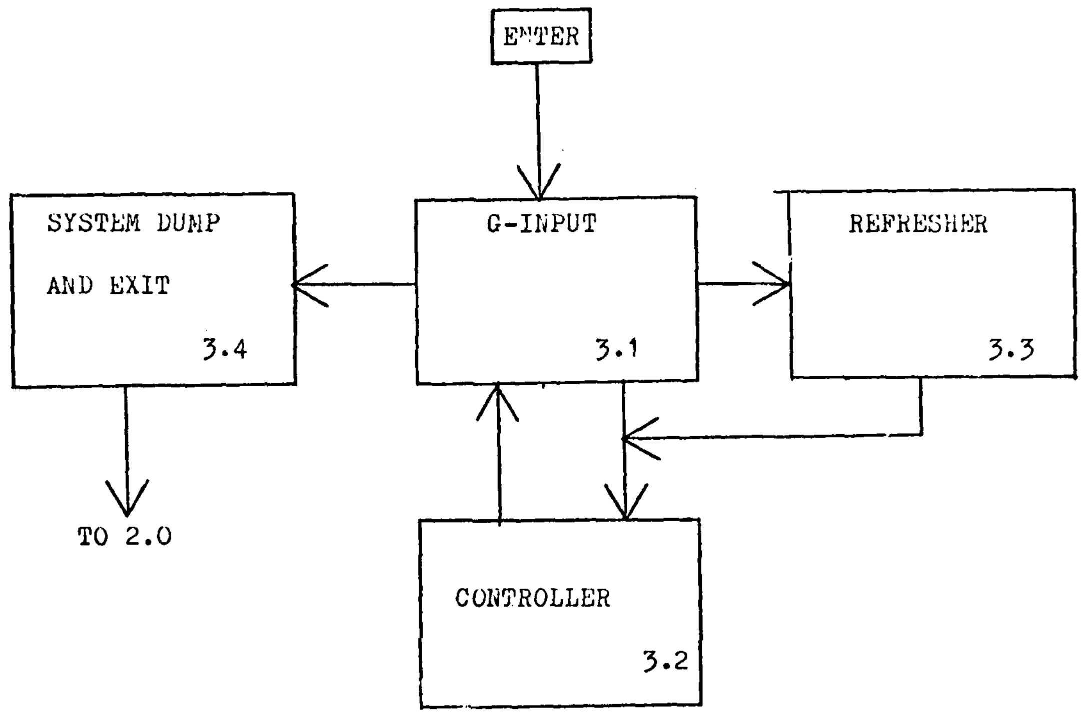


Figure IV-7. Controller Software Structure for the PSC

(Breakdown of Module 3.0)

Module 3.1 - G-Input Module. Module 3.1 is simply a keyboard input module. It accepts 0 through 9 as g inputs, treating 0 as 10 so the user may enter g values ranging from 1 to 10. Entering an "R" activates the Refresh Cycle, Module 3.3. Hitting the spacebar sends control to the System Dump and Exit Module, 3.4, where all the bladders are dumped and control is passed to the Decision Module, 2.0. If any value other than 1 through 9, R or spacebar is entered, the controller assumes the g value is unchanged from the last sample. If no key is pressed, the

Z-100 returns a NULL character, and the software assumes an unchanged g as for any erroneous entry.

Module 3.2 - Controller. Module 1.3, PSI/G Profile, determines the discrete pairs of the PSI/G relationship as described earlier. In Module 3.2, the g level closest to, but not exceeding, the sensed g is determined using a binary search. Figure IV-8 flowcharts the search.

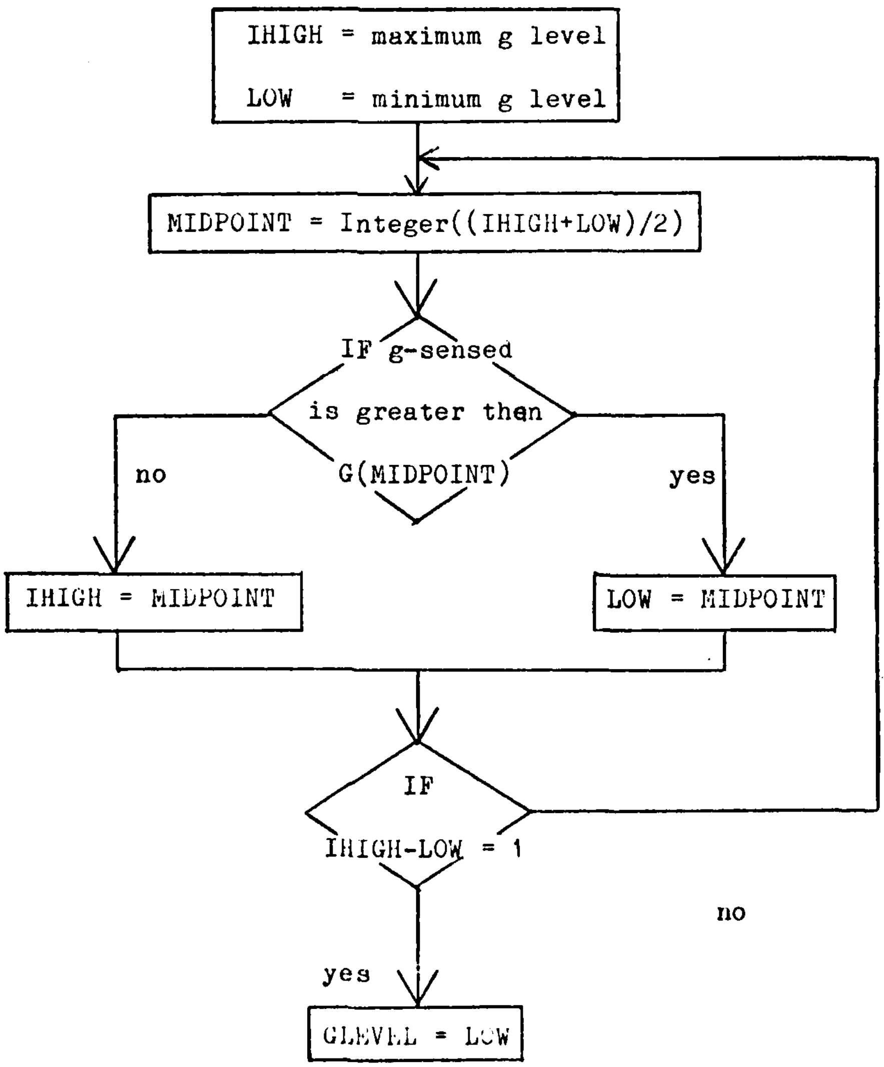


Figure IV-8. Flowchart of the Binary Search for the G-Level

This search locates the g-level by limiting the possible range of g values to half the size of the previous range of g values. The following table shows the values each time through the loop for the case where there are ten levels and the value being searched for is between level 7 and level 8.

Iteration	LOW	MIDPOINT	IHIGH
0	0	5	10
1	5	7	10
2	7	8	10
3	7	-	8

Since IHIGH minus LOW equals 1, the GLEVEL is 7. Thus, the desired pressure is in the pressure array at the level of seven. This method finds the level faster than stepping through the g values and comparing each to the sensed g. The binary search eliminates half the possibilities with each iteration while stepping through only eliminates one level for each iteration.

If the new level is different than the level of the last sample, the system tries to settle at a new desired pressure and has all new threshold pressures.

The next part of Module 3.2's code compares each bladder pressure with the desired pressure to decide the state of the fill and dump valves. As expected, the fill valve is turned on to increase pressure, the dump valve in turned on to decrease pressure, and both are turned off to maintain the current pressure. Once the valve states are adjusted, the controller returns to sample the g again. Thus, while the new g value is being determined, the valves are permitting the bladders to inflate, deflate, or hold.

<u>Module 3.3 - Refresh Cycle</u>. The refresh cycle is explained, and an example is presented, in the Module 1.3 discussion. The code contains two nested loops. The inner one loops within a given state, monitoring the pressure of the BOC until it reaches the DDP, then exits to the outer loop. The outer loop steps through each state until all have been achieved in turn. Then control returns to the Controller Module, 3.2, where the maintenance of desired pressure resumes. The inner loop also maintains the desired pressure for all the bladders that are not being dumped for that particular state.

<u>Module 3.4 - System Dump and Exit</u>. When invoked with a keyboard entry of "spacebar", Module 3.4 turns all the dump valves on and all the fill valves off to deflate the suit before relinquishing control to the Decision Module, 2.0. Once a bladder's pressure drops below 0.2 PSI, its dump valve is turned off. Once all the dump valves are off, the code returns to the decision module.

<u>Module 2.0 - Decision Module</u>. The Decision Module presents a menu of selections for the user. The user may run the controller and inflate a g-suit, exit the PSC and return to CP/M, or go to any part of the programmable portion to revise the g-suit parameters.

Summary

This chapter presents the design of the PSC starting with the software requirements, then developing the controller algorithm, diagramming the software modules, and finally, explaining each module.

The code listing is in Appendix A, a User's Guide is in Appendix E, and a Data Dictionary is in Appendix F. A thorough understanding of the code and its design is not necessary to use the PSC. However, the user may better test the concept of sequential inflation if the PSC is clearly understood.

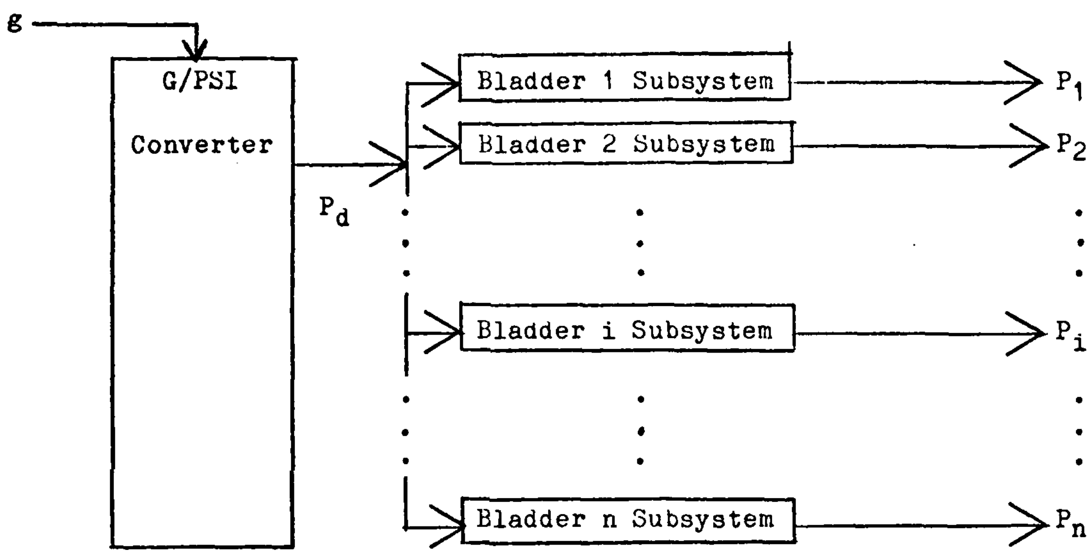
V. Testing, Analysis, and Results

This chapter presents the two bladder system from a controls viewpoint. First, a qualitative overview diagrams and explains the bang-bang sampled-data closed-loop control system for a single bladder subsystem. Next, in a quantitative analysis, the bladder transfer functions are investigated for each bladder's inflation and deflation profiles assuming linearity. Then, a transient analysis compares the inflation and deflation profiles for the theoretical versus experimental bladders to determine the goodness of the linear model.

Qualitative Overview

The concept of a multiple bladder g-suit controller implies a multiple input-multiple output system. However, each bladder functions independently, so, each system output is tied directly to a system input. Therefore, the complete g-suit control system is an accumulation of subsystems, each having a single input and a single output. Each subsystem utilizes the desired pressure, P_d, generated from the current g-value. Thus, a system consisting of n bladders has one input, g, and n outputs, the n bladder pressures. Figure V-1 shows a block diagram of an n-bladder system.

Internally, the system converts the current g-value to P_d and feeds it to each subsystem. The subsystems, then, are the focus of this analysis. A subsystem has one input, P_d, and one output, the actual bladder pressure, P_i. P_i is fed back for comparison with P_d. Figure V-2a shows a block diagram of one subsystem. The pressure sensor simply converts PSI to volts for comparison to a voltage that corresponds

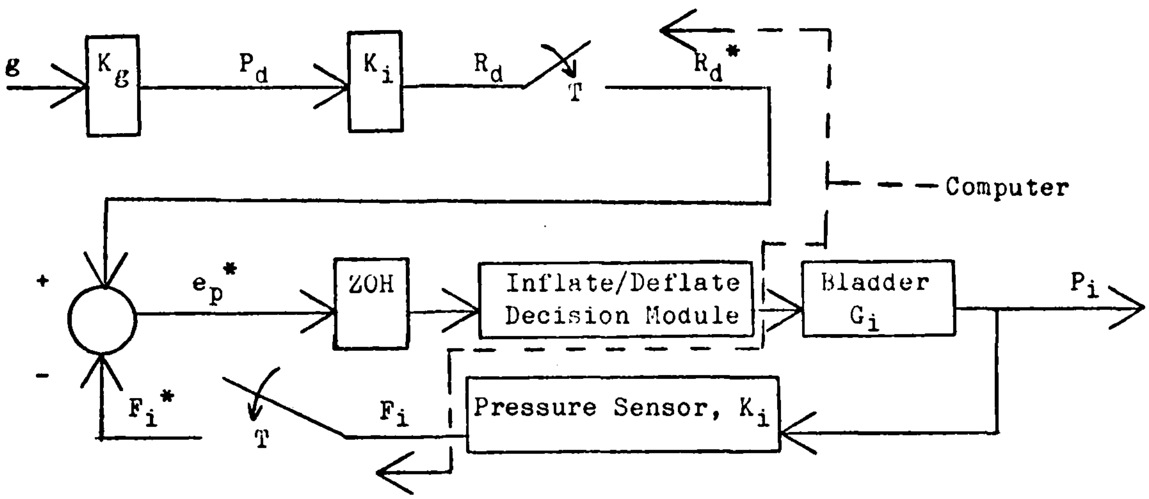


g - g-value input

P_d - desired bladder pressure

$P_1, P_2, \ldots, P_i, \ldots, P_n$ - pressure in bladders 1, 2,..., i,..., n

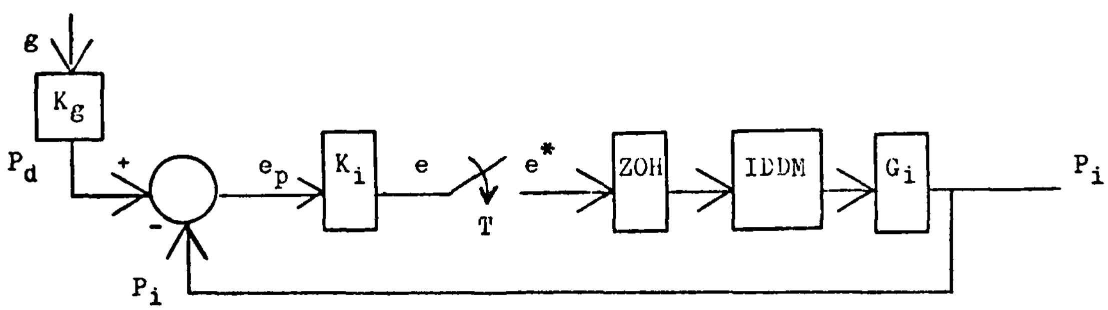
Figure V-1. Single-Input, n-Output Multiple Bladder System



P_d - desired bladder pressure, PSI
R_d - voltage representation of P_d, volts
P_i - actual pressure in bladder i, PSI
F_i - voltage representation of P_i for feedback, volts
K_g - programmed g to PSI conversion factor, PSI/g
K_i - pressure transducer constant, volts/PSI
G_i - transfer function of bladder i, PSI/volts

Figure V-2a. Bladder Subsystem

For analysis purposes, Figure V-2a is redrawn into an equivalent block diagram as shown in Figure V-2b.



IDDM - Inflate/Deflate Decision Module

Figure V-2b. Equivalent Block Diagram of Figure V-2a to the desired pressure. The comparator, or summing junction, of Figures V-2a and V-2b is in the computer and simply determines if P_i is larger than, equal to, or less than P_d. The difference, or error,

$$e_p = (P_d - P_i)$$

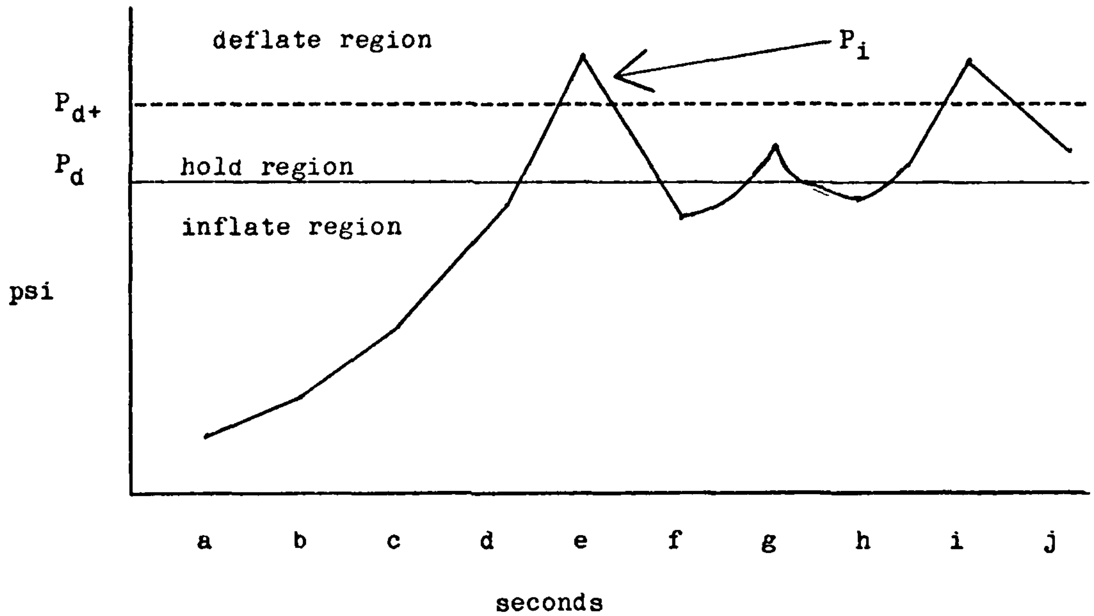
drives the Inflate/Deflate Decision Module (IDDM) which decides the state of the valves that fill and dump the bladder. This module is explained in the next subsection. The block labeled "Bladder G_i" represents the transfer function of the bladder. Its input is either full supply pressure or zero supply pressure. The determination of the experimental bladders' transfer functions is explained in the qualitative analysis.

IDDM. The purpose of the IDDM is to decide if the bladder needs to inflate or deflate based on P_i and P_d. The following table lists the decision criteria:

If P_i is:	P_d, then:
less than	inflate
equal to	hold
greater than	deflate

In reality, the "equal to" criteria is satisfied when P_i exceeds P_d by no more than a specified amount. This is the pressure window discussed in Chapter IV. Figure V-3 illustrates the desired pressure window concept and how it is used to determine the valve state. Now, if the error term, e_p, is negative and its magnitude is less than the difference between P_{d+} and P_d, the valve is in the hold state. If e_p is negative and its magnitude is greater than the window magnitude, then

then the valve is in the dump state because P_i is greater than desired. If e_p is positive, the valve is in the fill state. Hence, the IDDM functions as a three position switch to increase, hold, or decrease the bladder pressure.



P_d - desired pressure - bottom of pressure window

P_{d+} - top of pressure window

at time:	the valve state is:
a, b, c, d	fill
e	dump
f	fill
g	hold
h	fill
i	dump
j	hold

Figure V-3. Illustration of Pressure Window and Valve State Determination

Quantitative Analysis - Characteristics of the Two Experimental Bladders

Figures V-2a and V-2b represent the bladder transfer functions as G_i. In reality, a given bladder has an Inflation Transfer Function (ITF) and a Deflation Transfer Function (DTF). The transfer functions are determined using experimental inflation and deflation profiles and graphical techniques for linear systems (D'Azzo and Houpis, 1966:662-5). The inflation and deflation profiles for each bladder are shown in Figures V-4 through V-7. Each figure displays the theoretical and experimental inflation or deflation profiles for a single bladder.

Transfer Function Determination. The first step in determining the transfer function is to generate a response to step input profile on the strip chart. The experimental inflation profiles shown in Figures V-4 and V-5 appear similar to the general form of a second order transfer function. The experimental deflation profiles in Figures V-6 and V-7 appear similar to the general form of a first order transfer function (D'Azzo and Houpis, 1966:664). The general forms of the ITF's and DTF's are listed in Table V-1.

Table V-1. General Form of the ITF's and DTF's for First and Second Order Systems

	Order	Transfer Function
Inflation	2	$G(s) = 1/(s+1/T_1)(s+1/T_2)$
Deflation	1	$G(s) = KTs/(1+Ts)$

(D'Azzo and Houpis, 1966:663)

Thus, from the data it can be concluded that the plant, the bladder, is a Type-0 transfer function. A Type-0 linear control system is referred

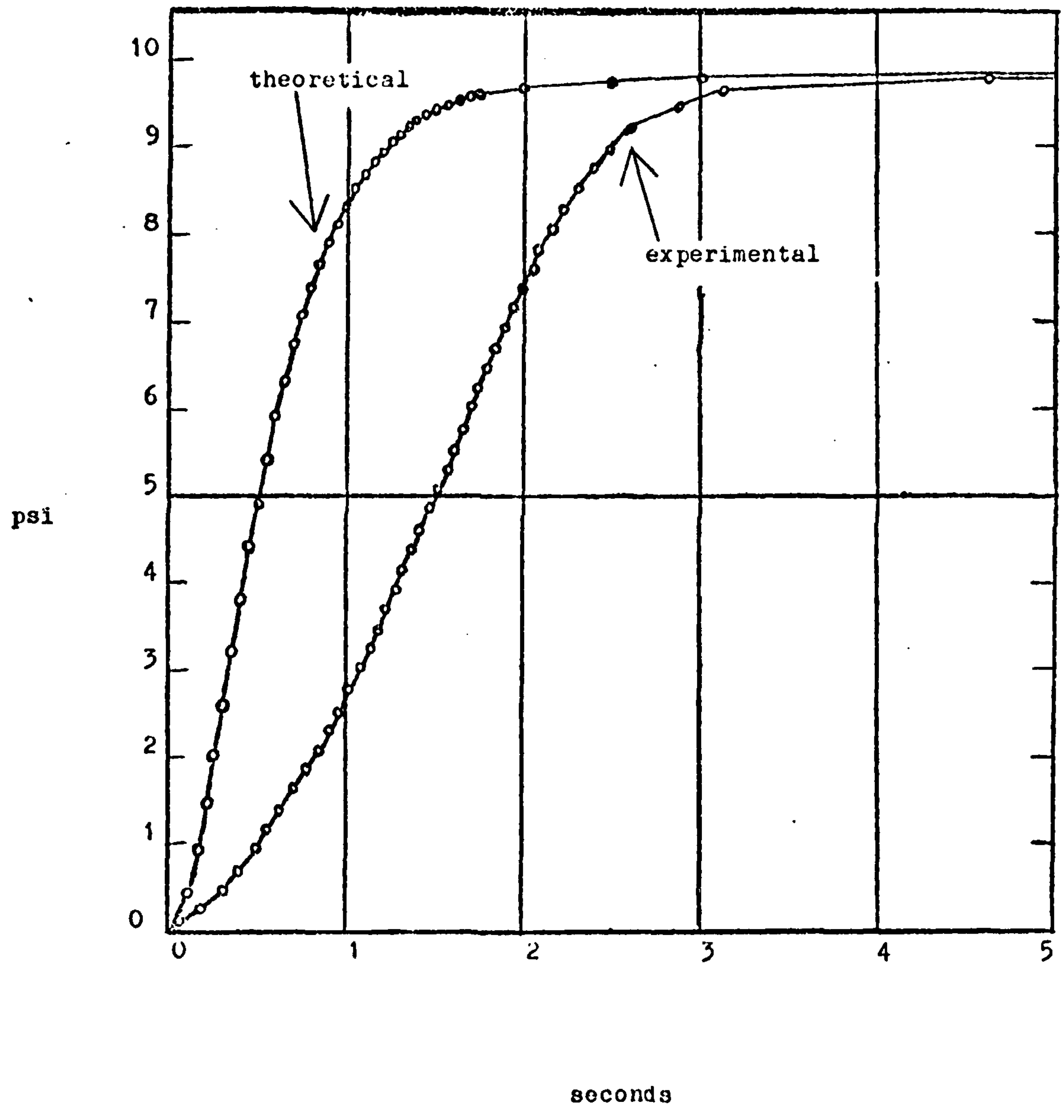


Figure V-4. Bladder Number One Inflation Profile
Theoretical and Experimental Response to Step Input

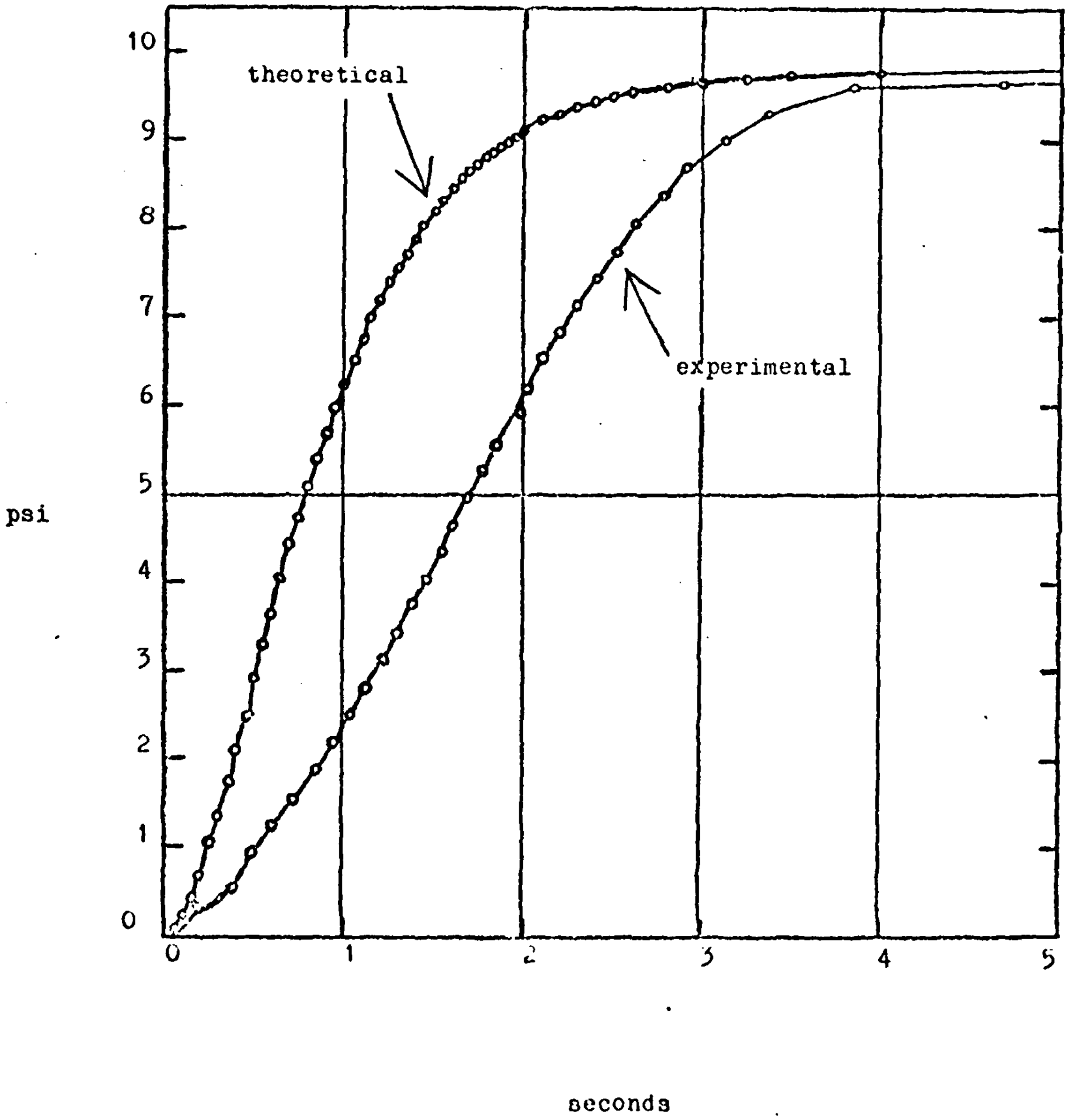


Figure V-5. Bladder Number Two Inflation Profile
Theoretical and Experimental Response to Step Input

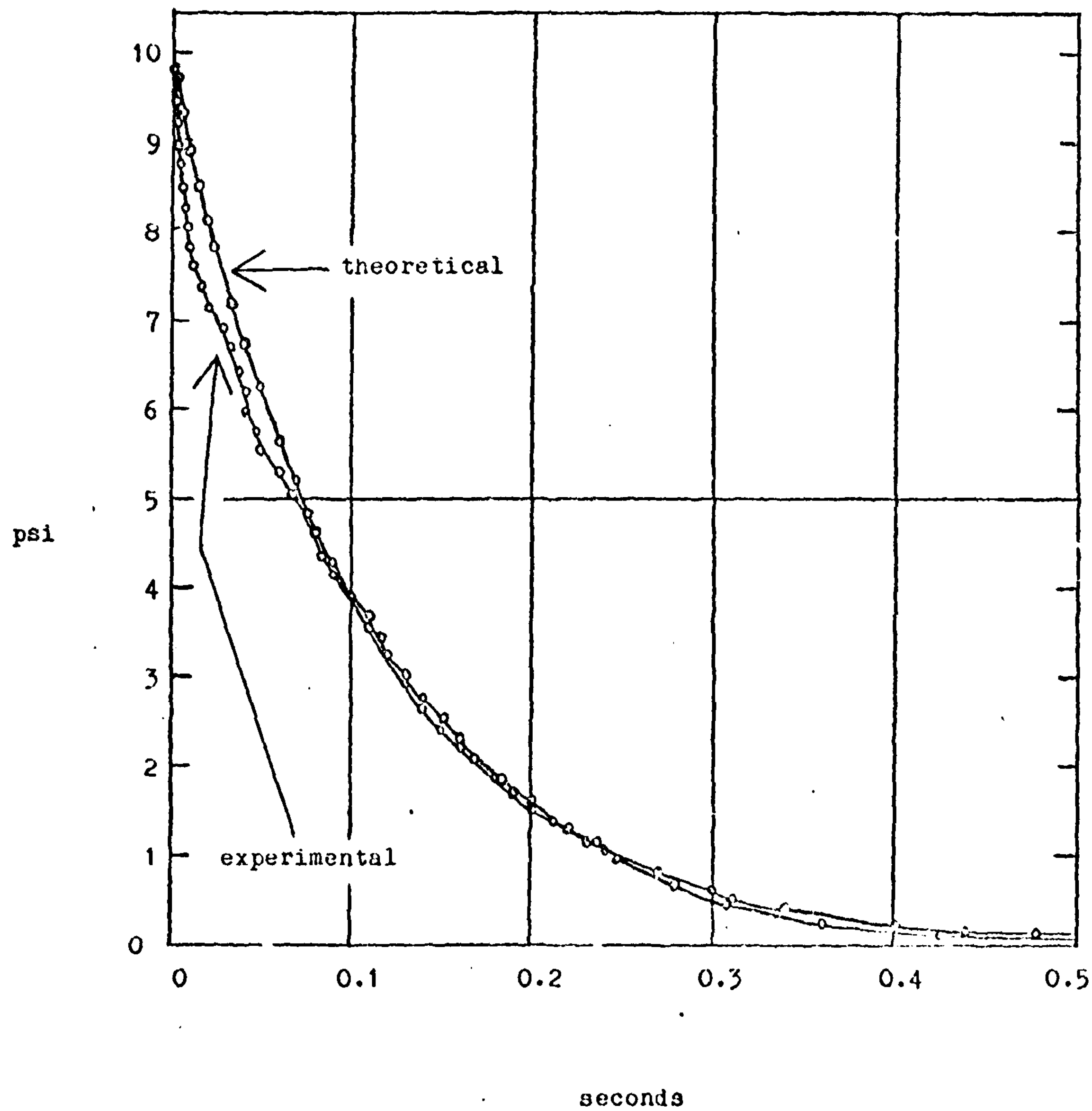


Figure V-6. Bladder Number One Deflation Profile
Theoretical and Experimental Response to Step Input

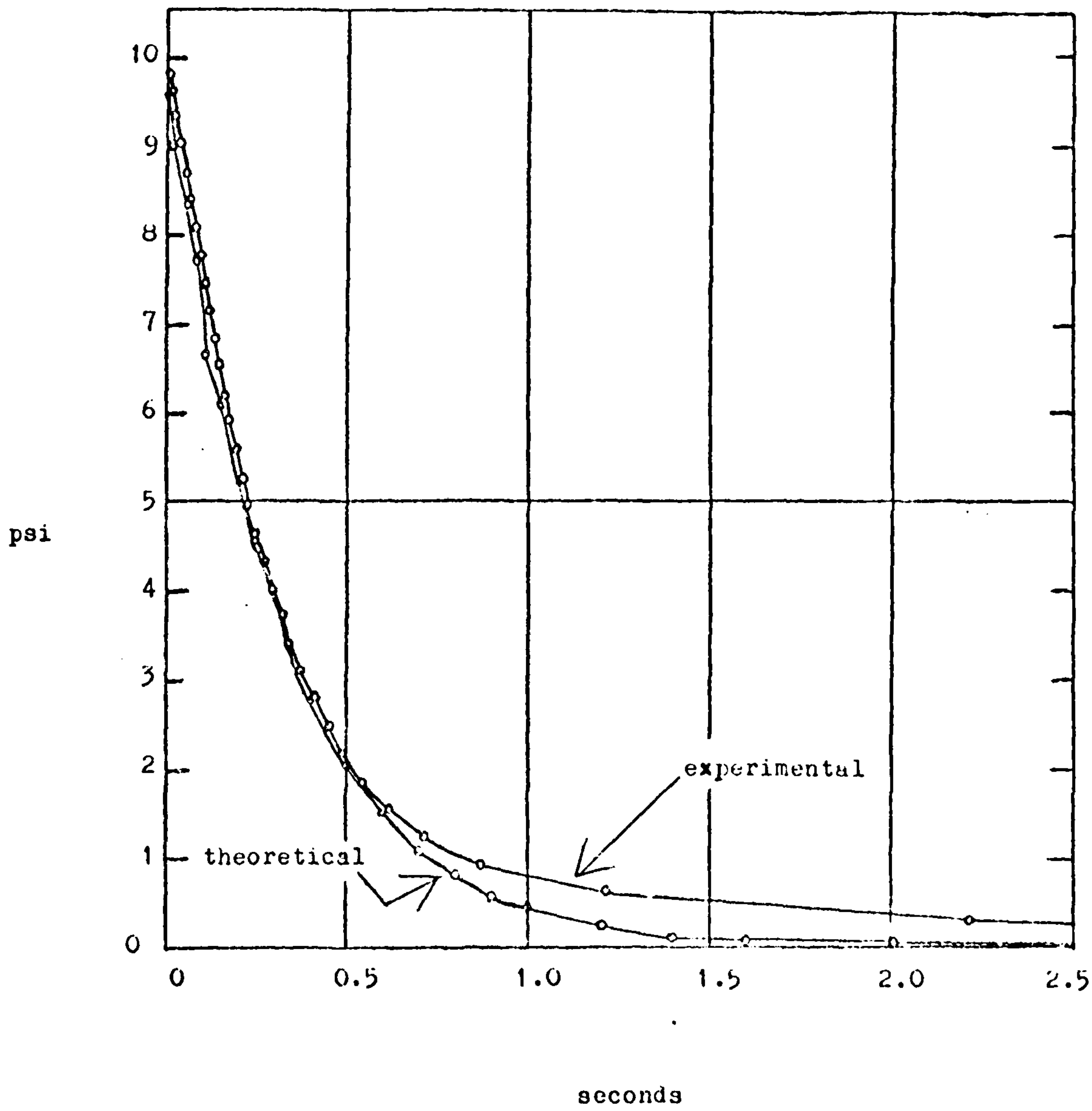


Figure V-7. Bladder Number Two Deflation Profile
Theoretical and Experimental Response to Step Input

to as a regulator (D'Azzo and Houpis. 1975:178-9) and for a given P_d there always exists a finite steaty-state error, i.e., $e_{p_{ss}}$ does not equal zero. This characteristic exists for the nonlinear Type-0 plant of this thesis as borne out by Figure V-3.

Using the graphical techniques described by D'Azzo and Houpis to determine of the second order (1965:663-5), and first order (1965:662-3) transfer functions yields the constants listed in Table V-2.

Table V-2. Graphically Determined Constants for ITF's and DTF's

	Bladder 1	Bladder 2
ITF	T_1 = 0.317	T_1 = 0.470
	T_2 = 0.274	T_2 = 0.449
DTF	K = 9.79	K = 9.79
	T = 0.108	T = 0.320

The next subsection compares the theoretical inflation and deflation characteristics with the experimental inflation and deflation characteristics to determine the goodness of the linear models.

Transient Analysis - Comparison of Experimental and Theoretical Bladders

The values in Table V-2 are substituted into the transfer functions of Table V-1. The data for the theoretical profiles in Figures V-4 through V-7 is generated using TOTAL (Version 3.0, (c) 1980, Stanley J. Larimer), a software package capable of producing the time response curve for a given transfer function and a specified input. The desired step input is 10 PSI for this attempt. The actual step used to generate the data is 9.79 PSI.

ITF's. The theoretical inflation profiles shown in Figures V-4 and V-5 for bladders 1 and 2 are much different than the experimental profiles. The experimental inflation profiles are more damped , but increasing the damping factor of the theoretical profiles does not improve the "fit" enough to call them similar. The graphical technique employed assumes T_1 and T_2 are "appreciably" different. In the analysis, T_1 and T_2 are very close in magnitude, so this technique does not produce a good model. There are probably some nonlinearities involved with bladder inflation. It is beyond the scope of this research to investigate these nonlinearities. Apparently, these nonlinearities are sufficient to render the linear model ineffective in representing bladder inflation. Indeed, further research may expose a valid linear model for inflation via a different approach. Perhaps the transfer function can be determined by locating the poles closer to the origin to increase the rise time, and/or adding a zero in the numerator of the second order transfer function of Table V-1. Another option is to determine the transfer function from the frequency response using Bode Plots. Closed loop testing with a sinusoidal g-input is also a viable alternative (D'Azzo and Houpis, 1975:242-60).

DTF's. Figures V-6 and V-7 show the DTF's to be very good models of the actual bladder transfer functions. For Bladder 1, the only discrepancy occurs in the first 0.06 seconds of deflation. Some of the difference can be attributed to inaccurate reading of the values on the strip chart. Even at high speed, the strip chart values for hundredths of a second are difficult to read accurately.

For Bladder 2, the only descrepancies occur below 1.0 PSI. In

Chapter III, Figure III-2 illustrates the theoretical concept of an optimal bladder size based on deflation time. The optimal size is smaller than the thigh bladder, Bladder 1, and much smaller than the abdominal bladder, Bladder 2. From the figure, as bladder size increases, deflation time increases drastically, suggesting the onset of nonlinear traits for increasing bladder size. In this test, both bladders deflate linearly for the first 0.5 seconds, but the larger bladder has 2.0 PSI yet to deflate while the smaller bladder's deflation is complete. It is soon after this point that the nonlinearities appear.

Even though slight nonlinearities are present in the large bladder below 1.0 PSI, it can be said that the theoretical transfer functions for deflation model the system well.

Summary

This chapter presented a qualitative overview of a multiple bladder system and quantitatively examined the specific bladders used in this research. The overall system is a combination of subsystems, one for each bladder in the g-suit. Each subsystem is a bang-bang closed-loop control system in itself.

The bladders used in this research exhibit nonlinear inflation characteristics but linear deflation characteristics. Before using the PSC to operate a multiple bladder sequentially inflatable g-suit, the characteristics of the suit being used should be evaluated. It is hoped that this analysis of bladder response provides a starting point for a deeper investigation of g-suit bladders, leading to the development of a better g-suit.

VI. Conclusions and Recommendations

Conclusions

The sponsor's requirements presented in Chapter II have been met. The next step is to try the PSC on a prototype suit and observe its operation.

The bladder inflation experiment of Chapter III exposed the phenomena of long term expansion drop and short term pressure drop, noting that short term pressure drop is the more destructive of the two.

The software design presented in Chapter IV is intended to be generic to any g-suit configuration, even one in which some parameter other than pressure is the feedback parameter. The feedback variable is simply compared to a desired value to determine if inflation or deflation is necessary. Since the input variable is adjusted using a programmable relationship, the PSC may be useful for an input parameter other than g. In other words, the PSC, although designed for g-suit operation, is basic enough to allow application in other areas.

The bladder evaluation in Chapter V showed inflation to be nonlinear and deflation linear. An acceptable model for deflation is developed but an inflation model is beyond the scope of this thesis.

Recommendations

Before the PSC can be used, a g-suit capable of multiple bladder sequential inflation must be fabricated. The theoretical concept of an optimal bladder size warrants investigation. Experimentation on bladders of varying sizes, fabrics, and supply pressures will provide information valuable to the design of a prototype g-suit. The criteria of optimization initially include inflation time, deflation time, short term pressure drop, long term expansion drop, and supply pressure. Some of these may be eliminated or made constant based on results of initial experimentation. Once an optimal bladder has been determined, a g-suit can be designed to incorporate it for best performance. Indeed, different bladders may exhibit characteristics desirable for a specific application. For example, one bladder size may be good for applying pressure to the calf area but ineffective in the abdominal region.

Further research may expose a valid linear model for inflation of the air bladders. Perhaps the transfer function can be determined by locating the poles closer to the origin than they are in the model developed in Chapter V. Adding a zero in the numerator may also help increase the rise time and improve the model. Another option is to determine the transfer function from the frequency response using Bode Plots. Closed-loop testing with a sinusoidal g-input is also a viable alternative (D'Azzo and Houpis, 1975:242-60).

The controller portion of the code should be scrutinized for unnecessary delays that can be eliminated. The controller is written to perform efficiently, but since computational delays are of great importance, any improvement in computation time will improve the PSC's ability to maintain the desired bladder pressure.

Both the input and output portions of the controller software are developed for the two bladder system and for keyboard input of the current g. They must be modified for centrifuge testing and for interfacing with the experimental g-suit once it is fabricated. As before, executation time must be minimized for effective operation.

Last, from the standpoint of safety, it is recommended that a manual abort be installed that can be activated by the subject or the observer in the event of system failure to prevent injury and suit damage. The system should be tested on a dummy first, followed by a subject at rest, and finally in the centrifuge.

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Appendix A

SOFTWARE LISTING

for

PSC

a

PROGRAMMABLE SOFTWARE CONTROLLER

for a

MULTIPLE BLADDER SEQUENTIALLY INFLATABLE G-SUIT

```
1 REM ***************************************************************
2 REM *          PSC - Programmable Software Controller
3 REM *
4 REM * date: 15 SEP 83                  author: Jerry L Marcu, 2LT
5 REM * FUNCTION: The program PSC is designed to operate a sequentially
6 REM * inflatable, multiple bladder G-suit using open-loop, digital
7 REM * control.  Modules 1.0 through 1.4 allow the user to program
8 REM * the characteristics of the G-suit being tested into the
9 REM * PSC.  Module 2.0 allows the user to decide between operating
10 REM* the suit as programmed, revising the characteristics, or
11 REM* quitting the PSC.  Modules 3.0 through 3.4 perform the
12 REM* controlling function.  The user is always in control of the
13 REM* PSC and may direct its operation from the keyboard.
14 REM*
15 REM***************************************************************
21 REM *                 1.0 USER INPUT MODULE
22 REM *          see page P1 of the data dictionary
23 REM * variables established: B( ), BLADDER( ), BPSI( )
24 REM * CALIBRATION( ), G( ), GLAST, IPARALLEL( ), KBOC( ),
25 REM * KDUMP( , ), NUMDUMP( ), P( ), PORT, PORT( ), RPSI( ),
26 REM * THRESHHOLD( , ), TURNON( ), USER$, VALVE( ), WORD, Z$
27 REM * variables changed: PORT(1), PORT(2), USER$, Z$
28 REM * variables used: B( ), BLADDER( ), G( ), IPARALLEL( ),
29 REM * KBOC( ), KDUMP( , ), L, N, NUMDUMP( ), NUMGEES, NUMSTATES,
30 REM * P( ), RPSI( ), TURNON( )
31 REM **************************************************************
40 DEFINT I-N: GLAST = 0: WORD = 0: PORT = &H18: PORTG = &H1A
100 GOSUB 20060
110 PRINT "PLEASE ENTER YOUR NAME ":PRINT:PRINT
120 Z$ = INPUT$(1)
130 IF Z$ <> CHR$(13) THEN    USER$ = USER$+Z$: GOTO 120
140 PRINT "YOUR NAME IS ";USER$;"....DID I GET THAT RIGHT?";
150 GOSUB 20000
160 IF Z$ <> "Y" THEN PRINT:PRINT:PRINT "PLEASE TELL ME AGAIN!":
                   USER$ = CHR$(0):GOTO 100
              ELSE GOSUB 20050
170 PRINT "HELLO, ";USER$;", AND WELCOME TO THE WORLD OF SEQUENTIAL G-SUITS!"
180 PRINT:PRINT "Please set the shift key to 'CAPS LOCK'":GOSUB 20020
190 PRINT:PRINT "TO PROGRAM YOUR G-SUIT, PLEASE ANSWER THE QUESTIONS AS THEY":
    PRINT "APPEAR ON THE SCREEN.  A 'Y'(YES) OR 'N'(NO) REPLY CAUSES THE ":
    PRINT "PROGRAM TO CONTINUE.  AN 'X'(EXIT) TERMINATES THE PROGRAM."
200 PRINT:PRINT "WHEN ASKED FOR A NUMBER, ENTER THE NUMBER OF YOUR CHOICE AND":
    PRINT "A CARRAIGE RETURN.":PRINT
210 PRINT "IF YOU ENTER A QUANTITY INCORRECTLY, CONTINUE ON.  YOU WILL HAVE":
    PRINT "SEVERAL OPPOTUNITIES TO MAKE CORRECTIONS AND CHANGES."
220 PRINT CHR$(11);"READY?":GOSUB 20020
233 DIM PORT(24),CALIBRATION(24)
234 DIM BLADDER(24),TURNON(24),KBOC(24),RPSI(24),NUMDUMP(24),KDUMP(24,24)
235 DIM P(51),G(51),B(51)
236 DIM THRESHHOLD(24,1),BPSI(24),VALVE(24),IPARALLEL(24)
237 PORT(1) = &H1A: PORT(2) = &H19
240 GOSUB 2000
245 GOSUB 2700
250 GOSUB 3000
260 GOSUB 4000
270 GOSUB 20050:PRINT "DO YOU WISH TO PROGRAM A REFRESH CYCLE?":GOSUB 20000
272 IF Z$ = "Y"  THEN GOSUB 7000
280 PRINT "WOULD YOU LIKE A PRINTOUT OF YOUR G-SUIT CHARACTERISTICS?";
290 GOSUB 20000
300 IF Z$ <> "Y" THEN GOTO 840
310 LPRINT CHR$(12):LPRINT "BY LOCATION.....":LPRINT:LPRINT:
    LPRINT ,"BLADDER","BLADDER","PRESSURE":
    LPRINT ,"LOCATION","SEQUENCE","THRESHOLD":
    LPRINT ,"NUMBER","NUMBER","FACTOR"
320 LPRINT "ABDOMINAL  ":LPRINT "BLADDER(S)"
```

```
330 FOR I = N TO (2*L+1) STEP -1
340 LPRINT ,I,B(I),TURNON(B(I))
350 NEXT I
360 LPRINT "LEG BLADDERS"
370 FOR I = 2*L TO 1 STEP -1
380 LPRINT ,I, B(I),TURNON(B(I))
390 NEXT I
400 LPRINT CHR$(11)
410 LPRINT "LISTED SEQUENTIALLY.....":LPRINT:LPRINT
420 LPRINT , "BLADDER","BLADDER","PRESSURE":
    LPRINT , "SEQUENCE","LOCATION"."THRESHHOLD":
    LPRINT , "NUMBER","NUMBER","FACTOR"
421 LPRINT CHR$(11)
422 FOR I = 1 TO N
423 IF IPARALLEL (I) <> 0  THEN  LPRINT "BLADDER";BLADDER(I);"INFLATES";:
                                 LPRINT "PARALLEL TO BLADDER";IPARALLEL(I)
424 NEXT I
425 LPRINT CHR$(11)
426 FOR I = 1 TO N
427 LPRINT "THE CALIBRATION FACTOR FOR THE BLADDER IN LOCATION";I;"IS";:
    LPRINT "CALIBRATION(I)
428 NEXT I
430 FOR I = 1 TO N
450 LPRINT , I, BLADDER(I), TURNON(I)
460 NEXT I
470 LPRINT CHR$(11);"G-LEVEL TO BLADDER PSI RELATIONSHIP"
480 LPRINT:LPRINT:LPRINT ,"G-LEVEL","BLADDER PSI":LPRINT
490 FOR I = 0 TO NUMGEES
500 LPRINT , G(I),SPC(3);P(I)
510 NEXT I
520 LPRINT CHR$(11):LPRINT "                         REFRESH CYCLE CHARACTERISTICS":
    LPRINT:LPRINT "STATE","BOC","DDP","DUMP BLADDERS":LPRINT
530 FOR I = 1 TO NUMSTATES
540 LPRINT I,KBOC(I),RPSI(I),KDUMP(I,1);
550 FOR II = 2 TO NUMDUMP(I)
560 LPRINT ",";KDUMP(I,II);
570 NEXT II
580 LPRINT:NEXT I
840 GOTO 20120
1990 REM ***********************************************************
1991 REM *      1.1 NUMBER AND SEQUENCE OF BLADDERS
1992 REM *      see page P2 of the data dictionary
1993 REM * variables established: N, L
1994 REM * variables changed: B( ), BLADDER( ), CALIBRATION( ),
1995 REM *                    N, L, Z$
1996 REM * variables used: n/a
1997 REM * calling modules: 1.0 USER INPUT, and 2.0 DECISION MODULES
1998 REM * modules called: 4.1, 4.2, 4.3
1999 REM ***************************************************************
2000 GOSUB 20050:INPUT "ENTER THE TOTAL NUMBER OF BLADDERS IN YOUR G-SUIT";N:
 PRINT
2010 PRINT "IS";N;"THE CORRECT NUMBER?";
2020 GOSUB 20000
2030 IF Z$ <>"Y"  THEN PRINT "TRY AGAIN!":PRINT:GOTO 2000
2040 GOSUB 20050:INPUT "ENTER NUMBER OF BLADDERS IN ONE LEG";L:PRINT
2050 PRINT "THERE ARE";L;"BLADDERS IN THE RIGHT LEG,"
2060 PRINT "         ";L;"BLADDERS IN THE LEFT  LEG,"
2070 PRINT "      AND";(N-2*L);"BLADDER(S) IN THE ABDOMEN...CORRECT?";
2080 GOSUB 20000
2090 IF Z$ <> "Y" THEN PRINT "TRY AGAIN!":PRINT:GOTO 2040
                  ELSE GOSUB 20050
2100 PRINT "NOW, YOU MUST TELL ME THE SEQUENCE OF INFLATION"
2110 PRINT:
     PRINT "NORMALLY, THE LEGS INFLATE IN PARALLEL, STARTING WITH THE BLADDER":
     PRINT "NEAREST THE FEET, AND SEQUENCING TOWARD THE HEAD.":
     PRINT "THE ABDOMEN INFLATES AFTER THE LEGS.":PRINT
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2120 PRINT "DO YOU DESIRE NORMAL INFLATION?";
2130 GOSUB 20000
2140 IF Z$ <> "Y" THEN GOTO 2190
2150 FOR I = 1 TO N
2160 BLADDER(I) = I
2165 B(BLADDER(I)) = I
2170 NEXT
2180 GOTO 2400
2190 GOSUB 20050:PRINT "OK, FANCY PANTS! HERE'S THE PLAN!":PRINT
2200 PRINT "I HAVE ASSIGNED A NUMBER TO EACH BLADDER ":
     PRINT "AND YOU MUST TELL ME THE ORDER OF INFLATION":
     PRINT "I'LL PRINT A SCHEMATIC OF THE BLADDER LAYOUT TO HELP YOU.":
     GOSUB 20020
2210 GOSUB 20050
2220 LPRINT "ABDOMINAL ":LPRINT "BLADDER(S)"
2230 FOR I = 1 TO (N-2*L)
2240 LPRINT ,,SPC(6);(N-I+1)
2250 NEXT
2260 LPRINT "LEG BLADDERS"
2270 FOR I = 2*L TO 1 STEP -2
2280 LPRINT ,,(I-1),I
2290 NEXT
2300 LPRINT ,SPC(13);"FOOT";SPC(11);"FOOT"
2310 LPRINT:LPRINT "IF YOU WISH TO INFLATE ANY BLADDERS IN PARALLEL,":
     LPRINT "JUST NUMBER THEM CONSECUTIVELY.  WE'LL CONNECT THEM LATER."
2330 GOSUB 20050
2340 PRINT "NOW, WHICH BLADDER DO YOU WISH TO INFLATE FIRST?"
2350 INPUT "      ";BLADDER(1)
2360 FOR I = 2 TO N
2370 INPUT "NEXT";BLADDER(I)
2380 NEXT
2390 GOSUB 20050
2400 PRINT "YOUR SEQUENCE IS AS FOLLOWS:":PRINT
2410 FOR I = 1 TO N
2420 PRINT "BLADDER NO.  ";BLADDER(I);"      IS IN INFLATION SEQUENCE";
                                     " POSITION";I
2425 B(BLADDER(I)) = I
2430 NEXT
2440 PRINT:PRINT "ARE YOU SATISFIED?";
2450 GOSUB 20000
2460 IF Z$ <> "Y" THEN PRINT  "TRY AGAIN!": PRINT:GOTO 2330
2470 PRINT "WOULD YOU LIKE A PRINTOUT OF YOUR SEQUENCE?";
2480 GOSUB 20000
2490 IF Z$ <> "Y" THEN GOTO 2550
2500 LPRINT CHR$(11)
2510 FOR I = 1 TO N
2520 LPRINT "BLADDER NO.  ";BLADDER(I);"    IS IN INFLATION SEQUENCE POSITION";I
2530 NEXT
2550 RETURN
2700 GOSUB 20050
2710 PRINT "You must now input the calibration factors for each transducer":
     PRINT
2720 PRINT "ARE THEY ALL THE SAME?": GOSUB 20000
2730 IF Z$ <> "Y"  THEN  GOTO 2780
2740 PRINT CHR$(11): INPUT "WHAT IS THE CALIBRATION FACTOR";X
2750 FOR I = 1 TO N
2760 CALIBRATION(I) = X :NEXT I
2770 GOTO 2820
2780 PRINT CHR$(11); "ENTER THE CALIBRATION FACTORS BY BLADDER POSITION":PRINT
2790 FOR I = 1 TO N
2800 PRINT"WHAT IS THE CALIBRATION FACTOR FOR BLADDER NO.":I;:
     INPUT CALIBRATION(I)
2810 NEXT I
2820 FOR I = 1 TO N
2821 PRINT "THE CALIBRATION FACTOR FOR THE BLADDER IN LOCATION";I;"IS";:
     PRINT CALIBRATION(I)
```

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2822 NEXT I
2823 PRINT: PRINT "ARE YOU SATISFIED WITH THE CALIBRATION FACTORS?"
2824 GOSUB 20000
2825 IF Z$ <> "Y" THEN  PRINT "TRY AGAIN!": GOTO 2700
2826 RETURN
3000 GOSUB 20050
3001 REM ************************************************************
3002 REM *                1.2 THRESHHOLD PERCENTAGES
3003 REM *       see page P3 of the data dictionary
3004 REM * variables established: none
3005 REM * variables changed: IPARALLEL( ), TURNON( ), Z$
3006 REM * variables used: BLADDER( ), L, N, USER$
3007 REM * calling modules: 1.0 USER INPUT, and 2.0 DECISION MODULES
3008 REM * modules called: 4.1, 4.2, 4.3
3009 REM ************************************************************
3010 PRINT "OK, ";USER$;", PLEASE SET THE PRESSURE ";:
     PRINT "THRESHHOLD FOR EACH OF THE BLADDERS":
     PRINT:PRINT "DO YOU NEED AN EXPLANATION?"
3020 GOSUB 20000
3030 IF Z$ <> "Y"  THEN  GOTO 3130  ELSE GOSUB 20050
3040 PRINT "For Sequential Inflation, a bladder begins to inflate based on the":
     PRINT "pressure in the bladder previous to it in the sequence.  The ":
     PRINT "pressure threshhold is a percentage of the desired final pressure":
3050 PRINT "for each bladder.":PRINT:PRINT"For example, if you wish to inflate":
     PRINT "bladder Y when bladder X is half pressurized, the pressure ":
     PRINT "threshhold of bladder X would be 0.50": GOSUB 20020
3055 GOSUB 20050
3060 PRINT:PRINT:PRINT "PARALLEL INFLATION:":PRINT:PRINT "If you want two ";
            "bladders to inflate in parallel, they must be ":
     PRINT "sequenced consecutively, with the actual value for Bladder 2"
3070 PRINT "set to the desired value, and the first bladder set very":
     PRINT "large.  If you wish to inflate Bladders 1 and 2 in parallel,":
     PRINT "set 1 to 100, and 2 to the desired threshhold for the next bladder"
3128 GOSUB 20020
3130 GOSUB 20050
3140 PRINT "NOW, ";USER$;", DO YOU WANT ALL THE BLADDERS TO HAVE THE SAME":
     PRINT "THRESHHOLD, WITH THE LEGS IN PARALLEL?";: GOSUB 20000
3145 TURNON(0) = -100
3150 IF Z$ <> "Y"  THEN  GOTO 3180
     ELSE  PRINT:INPUT "ENTER THE DESIRED THRESHHOLD (BETWEEN 0.0 AND 1.0)";
           TURNON(2)
3160 FOR I = 2 TO 2*L STEP 2
3161 TURNON(I) = TURNON(2):IPARALLEL(I) = 0
3162 TURNON(I-1) = 100:IPARALLEL(I-1) = I
3163 NEXT I
3164 FOR I = (2*L+1) TO N-1
3165 TURNON(I) = 100: IPARALLEL(I) = 0: NEXT I
3166 TURNON(N) = 100: IPARALLEL(N) = 0
3167 GOTO 3206
3180 GOSUB 20050
3190 PRINT "I WILL LIST YOUR BLADDERS IN SEQUENTIAL ORDER, YOU SUPPLY THE":
     PRINT "THRESHHOLD FACTORS.":PRINT:PRINT "REMEMBER, set the first of two ";
     "parallel bladder threshholds to 100":PRINT
3200 FOR I = 1 TO N-1
3201 PRINT "THE THRESHHOLD FOR BLADDER  ";BLADDER(I);
           " IN SEQUENTIAL INFLATION POSITION  ";I;" IS ";:INPUT  TURNON(I)
3202 IF TURNON(I) = 100  THEN IPARALLEL(I) = I+1  ELSE IPARALLEL(I) = 0
3203 NEXT I
3204 TURNON(N) = 100:IPARALLEL(I) = 0
3206 GOSUB 20050:PRINT:PRINT "THE THRESHHOLD FOR BLADDER";N;"IS SET TO 100, AN":
     PRINT "ARBITRARILY CHOSEN LARGE NUMBER.  BLADDER";N;"IS THE LAST IN":
     PRINT "THE SEQUENCE AND IT SHOULD NEVER REACH ITS THRESHHOLD.":GOSUB 20020
3210 GOSUB 20050
3220 PRINT "YOUR THRESHHOLD FACTORS IN SEQUENTIAL ORDER ARE AS FOLLOWS:":PRINT
3230 FOR I = 1 TO N
3231 PRINT "FOR BLADDER ";BLADDER(I);"  (SEQUENTIALLY NO.";I;")....";TURNON(I);
```

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     SPC(4);"PARALLEL TO BLADDER"; IPARALLEL(I)
3232 NEXT I
3250 PRINT:PRINT "ARE THERE ANY THRESHHOLD FACTORS YOU WOULD LIKE TO CHANGE?";
3260 GOSUB 20000
3270 IF Z$ <> "Y"  THEN GOTO 3320
3280 INPUT "FOR WHICH BLADDER (enter sequence number)";I
3290 INPUT "WHAT IS THE DESIRED THRESHHOLD FACTOR";TURNON(I)
3295 PRINT "DOES THE NEXT BLADDER INFLATE PARALLEL TO BLADDER";BLADDER(I):
     GOSUB 20000
3297 IF Z$ = "Y"  THEN  IPARALLEL(I) = I+1
3300 GOTO 3250
3320 PRINT "WOULD YOU LIKE A PRINTOUT OF YOUR SEQUENCE AND THRESHHOLDS":
     GOSUB 20000
3330 IF Z$ <> "Y"  THEN GOTO 3380 ELSE GOSUB 20050
3339 LPRINT CHR$(11)
3340 LPRINT ,"SEQUENCE NO.","POSITION   ","THRESHHOLD FACTOR":LPRINT
3350 FOR I = 1 TO N
3360 LPRINT ,SPC(5);I,SPC(5);BLADDER(I),SPC(8);TURNON(I)
3370 NEXT I
3380 RETURN
4000 GOSUB 20050
4001 REM *********************************************************
4002 REM *              1.3 PSI/ G PROFILE
4003 REM *       see page P4 of the data dictionary
4004 REM * variables established: PSIMAX, PSIMIN
4005 REM * variables changed: PSIMAX, PSIMIN, THRESHHOLD( , ), Z$
4006 REM * variables used:G( ),NUMGEES,P( ),THRESHHOLD( , ),TURNON( ),USER$
4007 REM * calling modules: 1.0 USER INPUT, and 2.0 DECISION MODULES
4008 REM * modules called: 1.3.1, 1.3.2, 1.3.3, 4.1, 4.3
4009 REM ************************************************************
4010 PRINT USER$;", it's time to input the relationship between the G-force":
     PRINT "and the desired bladder pressure.  There are two ways to input":
     PRINT "the information:"
4020 PRINT:
     PRINT "(1) a LINEAR equation, or,":PRINT "(2) a set of discrete ";:
     PRINT "pressures corresponding to G-levels, or":
     PRINT "(3) a pair of starting and incremental G- and pressure levels"
4030 INPUT"ENTER YOUR CHOICE(1,2,or 3)";J:GOSUB 20050
4040 INPUT"ENTER THE MAXIMUM ALLOWABLE BLADDER PRESSURE";PSIMAX
4050 IF PSIMAX > 10   THEN  PSIMAX = 10 :
     PRINT "The maximum allowable bladder pressure is 10 PSI!"
4060 PRINT:INPUT "ENTER THE READY PRESSURE (minimum allowable PSI)";PSIMIN
4070 IF PSIMIN < 0   THEN  PSIMIN = 0:
     PRINT "The minimum allowable bladder pressure is 0 PSI"
4080 ON J GOSUB  4500, 4800, 4900
4090 GOSUB 20050
4100 PRINT "HERE IS YOUR 'G-TO-PSI' RELATIONSHIP CHART.":PRINT:PRINT
4110 PRINT "FOR G's >= :",,"BUT < :","THE PSI IS:":PRINT:PRINT:
     PRINT SPC(3);" -",,G(1),SPC(3);P(0)
4120 FOR I = 1 TO (NUMGEES-1)
4130 PRINT SPC(3);G(I),,G(I+1),SPC(3);P(I)
4140 NEXT I
4150 PRINT SPC(3);G(I),," - ",SPC(3);P(I):PRINT CHR$(11)
4160 PRINT "DO YOU WISH TO CHANGE ANY OF THE PRESSURES?";:
     GOSUB 20000
4170 IF Z$ <> "Y"  THEN  GOTO 4220
4180 FOR I = 0 TO NUMGEES-1
4190 PRINT I,"UP TO G=";G(I+1),"PSI = ";P(I):NEXT I
4195 PRINT I,"     OVER";G(I),"PSI = ";P(I)
4200 INPUT "ENTER THE ROW OF THE PRESSURE TO BE CHANGED";I
4210 INPUT "ENTER THE NEW PRESSURE";P(I):GOTO 4160
4220 GOSUB 20050
4230 PRINT "DO YOU WISH TO CHANGE ANY OF THE G-LEVELS?";:
     GOSUB 20000
4240 IF Z$ <> "Y"  THEN  GOTO 4290
4250 FOR I = 0 TO NUMGEES-1
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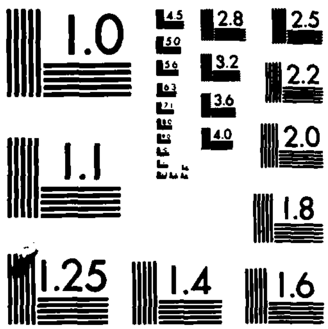
4260 PRINT I,"UP TO G=":G(I+1),"PSI = ";P(I):NEXT I
4270 INPUT "ENTER ROW OF THE G-LEVEL TO BE CHANGED":I
4280 INPUT "ENTER THE NEW G-LEVEL":G(I+1): GOTO 4220
4290 PRINT "DO YOU NEED TO SEE THE 'G-TO-PSI' CHART AGAIN?";:
     GOSUB 20000
4300 IF Z$ = "Y" THEN  GOTO 4090
4310 PRINT "WOULD YOU LIKE A PRINTOUT OF YOUR 'G-TO-PSI' CHART?";:
     GOSUB 20000
4320 IF Z$ <> "Y"  THEN  GOTO 4380
4330 LPRINT CHR$(11):LPRINT ,"G-LEVEL TO BLADDER PSI CHART":LPRINT:
     LPRINT "FOR G's >=:",,"BUT < :","THE PSI IS:":LPRINT:LPRINT:
     LPRINT SPC(3);"  -",,G(1),SPC(3);P(0):PRINT
4340 FOR I = 1 TO (NUMGEES-1)
4350 LPRINT SPC(3);G(I),,G(I+1),SPC(3);P(I):PRINT
4360 NEXT I
4370 LPRINT SPC(3);G(I),," - ",SPC(3);P(I)
4380 FOR I = 1 TO N
4390 FOR J = 0 TO NUMGEES
4400 THRESHHOLD(I,J) = TURNON(I) * P(J)
4410 NEXT J,I
4420 I = 0
4430 FOR J = 0 TO NUMGEES
4440 THRESHHOLD(I,J) = -100: NEXT J
4450 RETURN
4500 GOSUB 20050
4501 REM ************************************************************
4502 REM *      1.3.1 SINGLE POINT LINEAR RELATIONSHIP
4503 REM *      see page P5 of the data dictionary
4504 REM * variables established: GLEVEL, GSTEP, NUMGEES, PRESSURE,
4505 REM *                        SLOPE, YINTERCEPT
4506 REM * variables changed: G( ), P( ), Z$, all those established
4507 REM * variables used: PSIMAX, PSIMIN, USER$
4508 REM * calling module: 1.3 PSI/G PROFILE
     rem * modules called: 4.1, 4.2, 4.3
4509 REM ************************************************************
4510 PRINT USER$;", you may now enter the linear PSI per G relationship":
     PRINT "as a slope, PSI/G, and one sample pair, PSI and G.":PRINT:
     PRINT "Do you need an explanation?";:GOSUB 20000
4520 IF Z$ <> "Y"  THEN  GOTO 4560  ELSE GOSUB 20050
4530 PRINT CHR$(11):"FOR EXAMPLE,":PRINT:
     PRINT "Assume you want the pressure to increase 1.5 PSI for every":
     PRINT "1.0 G increase, and, you want to start inflating at 2G's.":PRINT
4540 PRINT "You would input 1.5 PSI/G as the slope, and 0 PSI at 2G":
     PRINT "for the sample value.":PRINT:PRINT  "OR,"
           "assume you want the pressure to increase 1.0 PSI for every"

4550 PRINT "2.0 G increase, and, you want 5 PSI at 3.5 G's.":PRINT:
     PRINT "You would input 0.500 PSI/G for the slope and 5 PSI at 3.5 G":
     PRINT "for the sample input.":PRINT:GOSUB 20020
4560 INPUT "ENTER THE SLOPE (PSI/G)";SLOPE
4570 INPUT "ENTER THE SAMPLE PRESSURE(PSI)";PRESSURE
4580 INPUT "ENTER THE SAMPLE G-LEVEL";GLEVEL
4590 YINTERCEPT = PRESSURE - SLOPE * GLEVEL : GOSUB 20050
4600 PRINT "The relationship between G and PSI is not 'really' linear, but,":
     PRINT "stepwise linear.  You must now select the G stepsize(sensitivity).":
     PRINT:PRINT "Do you need an explanation?";: GOSUB 20000
4610 IF Z$ <> "Y"  THEN  GOTO 4670  ELSE GOSUB 20050
4620 PRINT " The computer samples the G-force sporadically, not periodically":
     PRINT "or continuously.  In between samples, it updates the memory and":
     PRINT "turns the valves on and off as needed.":PRINT
4630 PRINT "In addition, the valves take time to open and close, thus, it is":
     PRINT "not possible to change the pressure by , say, 0.01 PSI, because":
     PRINT "of sensing time and valve actuation time":PRINT
4640 PRINT "The realistic limit on sensitivity, or minimum PSI change, ":
     PRINT "depends on the supply pressure, the number of bladders, and the":
     PRINT "rate of G acceleration.  Hence, it is ever changing." :PRINT
```

AD-A138 069 PSC A PROGRAMMABLE SOFTWARE CONTROLLER FOR A MULTIPLE BLADDER SEQUENTIALL..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. J L MARCU 2/2

UNCLASSIFIED DEC 83 AFIT/GE/EE/83D-41 F/G 6/11 NL

END



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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4650 PRINT "You may find a practical PSI sensivity through trial-and-error":
     PRINT "by starting with 1.0 g minimum stepsize and decreasing it until":
     PRINT "the system no longer works.  When the sensitivity gets too low"
4660 PRINT "the valves sputter as they continually overshoot and undershoot ":
     PRINT "the desired pressure.": GOSUB 20020
4670 GOSUB 20050
4680 INPUT "ENTER THE G-SENSITIVITY";GSTEP
4690 G(0) = 0:
     G(1) = (PSIMIN - YINTERCEPT)/SLOPE:
     P(0) = PSIMIN:
     I = 0
4700 WHILE P(I) < PSIMAX
4710 I = I+1:
     G(I+1) = G(I) + GSTEP:
     P(I) = SLOPE * G(I+1) + YINTERCEPT:
     WEND
4720 P(I) = PSIMAX:
     P(I+1) = P(I) + .5:
     NUMGEES = I
4730 RETURN
4800 GOSUB 20050
4801 REM ***********************************************************
4802 REM *       1.3.2 DISCRETE VALUE RELATIONSHIP
4803 REM *       see page P6 of the data dictionary
4804 REM * variables established: NUMGEES
4805 REM * variables changed: G( ), NUMGEES, P( )
4806 REM * variables used: PSIMAX, PSIMIN
4807 REM * calling module: 1.3 PSI/G PROFILE
4808 REM * modules called: 4.3
4809 REM ***********************************************************
4820 PRINT CHR$(11): PRINT "YOU MUST NOW INPUT SPECIFIC G-LEVELS AND THEIR":
     PRINT "CORRESPONDING BLADDER PRESSURES":
     PRINT:PRINT "YOUR LAST ENTRY WILL BE THE MAXIMUM PRESSURE PAIR"
4830 I = 0 :
     P(I) = PSIMIN:
     G(I) = 0
4840 WHILE P(I) < PSIMAX
4850 I = I+1
4860 PRINT "ENTER G-LEVEL NO.";I;", COMMA, PRESSURE LEVEL NO.";I:INPUT G(I),P(I)
4870 WEND
4880 NUMGEES = I: P(I+1) = P(I) + .5
4890 RETURN
4891 REM ***********************************************************
4892 REM * 1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP
4893 REM *       see page P7 of the data dictionary
4894 REM * variables established: GSTEP, NUMGEES, PSTEP
4895 REM * variables changed: G( ), GSTEP, NUMGEES, PSTEP
4896 REM * variables used: PSIMAX, PSIMIN
4897 REM * calling module: 1.3 PSI/G PROFILE
4898 REM * modules called: none
4899 REM ***********************************************************
4900 INPUT "AT WHAT G-LEVEL DO YOU WANT TO START INFLATING";G(1)
4910 PRINT "ENTER THE G-LEVEL AND CORRESPONDING PRESSURE INCREMENTS":
     PRINT:PRINT "FOR EVERY G-INCREASE OF";:INPUT GSTEP:
     PRINT "INCREASE THE PRESSURE BY";:INPUT PSTEP
4920 G(0) = 0:
     P(0) = PSIMIN:
     P(1) = P(0) + PSTEP:
     I = 1
4930 WHILE P(I) < PSIMAX
4940 I = I+1: G(I) = G(I-1) + GSTEP: P(I) = P(I-1) + PSTEP: WEND
4950 P(I) = PSIMAX: NUMGEES = I:P(I+1) = P(I) + .5
4960 RETURN
7000 GOSUB 20050
7001 REM ***********************************************************
7002 REM *               1.4 REFRESH CYCLE
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7003 REM *      see page P8 of the data dictionary
7004 REM * variables established: NUMSTATES
7005 REM * variables changed: KBOC( ), KDUMP( , ), NUMDUMP( ),
7006 REM * NUMSTATES, RPSI( )   variables used: USER$
7007 REM * calling modules: 1.0 USER INPUT, and 2.0 DECISION MODULES
7008 REM * modules called: 4.1, 4.3
7009 REM ***********************************************************
7010 PRINT "Alright then, "USER$;", you may now input the refresh cycle.  ":
     PRINT "Do you need an explanation?":GOSUB 20000
7020 IF Z$ <> "Y" THEN  GOTO 7080  ELSE GOSUB 20050
7030 PRINT "The refresh cycle is activated manually from the terminal by ":
     PRINT "hitting the 'R' key once (R for REFRESH).  The system will cycle":
     PRINT "through the refresh sequence and then resume response to G-input ":
     PRINT "as before."
7040 PRINT "To program the refresh cycle you must provide the system with":
     PRINT "a series of intermediate states to achieve.  The parameters of":
     PRINT "a single state are a Bladder Of Concern (BOC), its Desired Dump "
7050 PRINT "Pressure (DDP), and a set of Bladder Instructions (BI's).  ":PRINT:
     PRINT "NOTE: ALL BLADDER NUMBERS ARE BY POSITION ... NOT SEQUENCE!":PRINT
7060 PRINT "You specify a BOC, its DDP and the BI's for each state.  The ":
     PRINT "computer will open/close the valves as specified until the ":
     PRINT "BOC reaches its DDP"
7070 PRINT:PRINT "In achieving that DDP, the system reaches State 1 and":
     PRINT "may proceed to State 2.  It follows State 2's BI's, monitors the":
     PRINT "State 2 BOC until it achieves the State 2 DDP, and proceeds to":
     PRINT "State 3, etc.,..."
7080 INPUT "ENTER THE TOTAL NUMBER OF STATES IN YOUR REFRESH CYCLE"; NUMSTATES
7090 FOR I = 1 TO NUMSTATES
7100 PRINT "WHAT IS THE BOC FOR STATE";I;: INPUT KBOC(I)
7110 PRINT "WHAT IS THE DESIRED BOC DUMP PRESSURE FOR STATE";I;: INPUT RPSI(I)
7120 PRINT:PRINT "ENTER THE BI's FOR STATE";I:PRINT
7130 PRINT "STATE";I,:INPUT "- HOW MANY BLADDERS WILL DUMP"; NUMDUMP(I)
7140 FOR II = 1 TO NUMDUMP(I)
7150 PRINT "ENTER NO.";II;"OF";NUMDUMP(I);"DUMP BLADDER NUMBER(S)";:
     INPUT KDUMP(I,II)
7160 NEXT II
7170 NEXT I
7180 GOSUB 20050
7190 PRINT "                REFRESH CYCLE CHARACTERISTICS":PRINT:
     PRINT "STATE ","BOC","DDP", "DUMP BLADDERS":PRINT
7200 FOR I = 1 TO NUMSTATES
7210 PRINT I,KBOC(I),RPSI(I),KDUMP(I,1);
7220 FOR II = 2 TO NUMDUMP(I)
7230 PRINT ",";KDUMP(I,II);
7240 NEXT II
7250 PRINT:NEXT I
7260 PRINT "DO YOU WISH TO CHANGE ANY OF THE STATE INFORMATION?":GOSUB 20000
7270 IF Z$ <> "Y"  THEN GOTO 7340
7280 INPUT "ENTER THE STATE TO BE CHANGED":I
7290 INPUT "ENTER THE BOC,DDP,NO. OF DUMP BLADDERS";KBOC(I),RPSI(I),NUMDUMP(I)
7300 PRINT "ENTER THE DUMP BLADDER NUMBER(S)":PRINT
7310 FOR II = 1 TO NUMDUMP(I)
7320 INPUT ;KDUMP(I,II):NEXT II
7330 GOTO 7180
7340 GOSUB 20050:PRINT "DO YOU WANT A PRINTOUT OF THE STATE CHARACTERISTICS?":
     GOSUB 20000
7350 IF Z$ <> "Y" THEN GOTO 7430
7360 LPRINT CHR$(11):LPRINT"             REFRESH CYCLE CHARACTERISTICS":LPRINT:
     LPRINT "STATE","BOC","DDP","DUMP BLADDERS":PRINT
7370 FOR I = 1 TO NUMSTATES
7380 LPRINT I,KBOC(I),RPSI(I),KDUMP(I,1);
7390 FOR II = 2 TO NUMDUMP(I)
7400 LPRINT ",";KDUMP(I,II);
7410 NEXT II
7420 LPRINT:NEXT I
7430 RETURN
```

```
19990 REM ************************************************************
19991 REM *                    4.0 MISCELLANIA
19992 REM *        see page P15 of the data dictionary
19993 REM * MISCELLANIA contains the following submodules:
19994 REM *        4.1 RESPONSE - lines 20000 to 20010
19995 REM *        4.2 CONTINUE - lines 20020 to 20040
19996 REM *        4.3 CLEARSCREEN - lines 20050 to 20056
19997 REM *        4.4 SLOW CLEARSCREEN - lines 20060 to 20110
19998 REM ************************************************************
20000 PRINT " (Y/N;X-eXit)
20002 PRINT
20005 Z$ = INPUT$(1)
20010 IF Z$ = "x" OR Z$ = "X" THEN GOTO 20120  ELSE RETURN
20020 PRINT:PRINT "( hit RETURN to continue )"
20030 Z$ = INKEY$
20040 IF Z$ <> CHR$(13) THEN GOTO 20030 ELSE RETURN
20050 FOR I = 0 TO 25
20055 PRINT: NEXT I
20056 RETURN
20060 FOR I = 0 TO 25
20070 FOR J = 0 TO 5
20080 PRINT CHR$(32);
20090 NEXT J
20100 NEXT I
20110 RETURN
20120 GOSUB 20050
20121 REM ************************************************************
20122 REM *                    2.0 DECISION MODULE
20123 REM *        see page P9 of the data dictionary
20124 REM * variables established: none
20125 REM * variables changed: Z$
20126 REM * variables used: none
20127 REM * calling modules: none
20128 REM * modules called: 1.1, 1.2, 1.3, 1.4, 3.0, 4.3, 5.0
20129 REM ************************************************************
20140 PRINT "TO INFLATE THE G-SUIT....................type a  'G' for 'Go'"
20150 PRINT "TO CHANGE ANY G-SUIT PARAMETERS........type a  'C' for 'Change'"
20160 PRINT "TO QUIT THE PROGRAM.....................type a  'Q' for 'Quit'"
20170 Z$ = INPUT$(1)
20175 IF Z$ = "Q"  THEN END
20180 IF Z$ <> "C"  THEN GOTO 20270
20190 GOSUB 20050
20199 PRINT "                           MAJOR CHANGES":PRINT
20200 PRINT "TO INPUT A COMPLETELY NEW G-SUIT..................ENTER '1'";
      PRINT "TO INPUT A NEW SEQUENCE OF INFLATION.............ENTER '2'";
      PRINT "TO INPUT A NEW SET OF THRESHHOLD PRESSURES.......ENTER '3'"
20210 PRINT "TO INPUT A NEW PSI/G RELATIONSHIP................ENTER '4'";
      PRINT "TO INPUT A NEW REFRESH CYCLE.....................ENTER '5'";
      PRINT:PRINT:PRINT "                    MINOR CHANGES ONLY":PRINT
20220 PRINT "TO CHANGE PART OF THE SEQUENCE...................ENTER '6'";
      PRINT "TO CHANGE SOME PRESSURE THRESHHOLDS..............ENTER '7'";
      PRINT "TO CHANGE PART OF THE PSI/G RELATIONSHIP.........ENTER '8'"
20230 PRINT "TO CHANGE PART OF THE REFRESH CYCLE..............ENTER '9'";
      PRINT:PRINT:PRINT:
      PRINT "WHEN YOUR CHANGES ARE COMPLETE...................ENTER '0'"
20240 PRINT:PRINT:PRINT "YOUR SELECTION?"
20242 Z$ = INKEY$
20244 IF Z$ < CHR$(48) OR Z$ > CHR$(57)  THEN GOTO 20242
20246 I = VAL(Z$)
20250 ON I GOSUB 20280,2100,3000,4000,7000,2390,3210,4090,7180
20260 GOTO 20120
20270 IF Z$ = "G"  THEN  GOSUB 30000
20275 GOTO 20120
20280 FOR I = 0 TO 24
20290 BLADDER(I) = 0: TURNON(I) = 0: KBOC(I) = 0: RPSI(I) = 0: NUMDUMP(I) = 0:
      RPRT(I) = 0: VALVE(I) = 0: IPARALLEL(I) = 0: CALIBRATION(I) = 0
```

```
20300 NEXT I
20310 FOR I = 0 TO 51
20320 P(I) = 0: G(I) = 0: B(I) = 0
20330 NEXT I
20340 FOR I = 0 TO 24
20350 FOR J = 0 TO 24
20360 KDUMP(I,J) = 0
20370 NEXT J,I
20380 FOR I = 0 TO 24
20390 FOR J = 0 TO 51
20400 THRESHHOLD(I,J) = 0
20410 NEXT J,I
20420 GOSUB 240
20430 RETURN
29970 REM ***************************************************************
29971 REM *                3.0 G-SUIT CONTROLLER
29972 REM *       see page P10 of the data dictionary
29973 REM * calling module: 2.0 DECISION MODULE
29974 REM *
29975 REM * FUNCTION: Module 3.0 is a virtual module, that is, it is never
29976 REM * called by another module, it is just a header for the 3.0
29977 REM * submodules 3.1, 3.2, 3.4.  Its purpose is to inflate/deflate
29978 REM * the G-suit according to the parameters programmed in Module
29979 REM * 1.0, USER INPUT MODULE.  It controls by first sampling the
29980 REM * keyboard for the next G value (3.1 G-INPUT), determining the
29981 REM * desired pressure, checking the actual bladder pressures, and
29982 REM * adjusting the fill/ dump valves to achieve the desired pressure
29983 REM * (3.2 CONTROLLER).  Sequential inflation is accomplished by
29984 REM * restricting a bladder's inflation to those times when its
29985 REM * pressure is too low AND the bladder sequentially before it
29986 REM * has the reached the desired pressure threshhold (line 30194).
29987 REM *
29988 REM ****************************************************************
29990 REM ****************************************************
29991 REM *                3.1 G-INPUT
29992 REM *       see page P11 of the data dictionary
29993 REM * variables established: GSAMPLE, GSTRING$, IHIGH, LOW,
29994 REM * MIDPOINT       variables changed: those established
29995 REM * variables used: NUMGEES
29996 REM * calling module: none
29997 REM * modules called: 3.3, 4.3
29998 REM ****************************************************
30000 GSTRING$ = "1" :IHIGH = NUMGEES+1:LOW = 0:MIDPOINT=IHIGH\2
30002 GOSUB 20050
30004 PRINT "                   TO STOP THE PROGRAM.......HIT THE SPACER BAR"
30006 PRINT CHR$(11);CHR$(11);CHR$(11)
30008 GOTO 30020
30009 IHIGH = NUMGEES + 1: LOW = 0: MIDPOINT = IHIGH\2
30010 GSTRING$ = INKEY$
30020 IF GSTRING$ >= "1" AND GSTRING$ <= "9" THEN GSAMPLE = ASC(GSTRING$)-48:
      GOTO 30080
30030 IF GSTRING$ = "0"  THEN  GSAMPLE = 10: GOTO 30080
      ELSE IF GSTRING$ = "R"  THEN GOSUB 31000
30040 IF GSTRING$ = " "  THEN GOTO 30280
30080 IF GSAMPLE < G(MIDPOINT)  THEN IHIGH = MIDPOINT   ELSE  LOW = MIDPOINT
30090 IF IHIGH-LOW = 1  THEN J = LOW  ELSE MIDPOINT = (IHIGH+LOW)\2:GOTO 30080
30100 IF G(J) = GLAST  THEN  GOTO 30140
30110 FOR I = 1 TO N
30120 VALVE(I) = 0: NEXT I
30130 GLAST = G(J)
30140 FOR I = 1 TO N
30150 BPSI(I) = INP(PORT(B(I))) * CALIBRATION(B(I))
30192 ON VALVE(I) GOTO 30198,30202
30194 IF BPSI(I) < P(J) AND BPSI(I-1) >= THRESHHOLD(I-1,J)
      THEN  VALVE(I) = 1:VALVE(IPARALLEL(I)) = 1
      ELSE  IF BPSI(I) > P(J+1)  THEN VALVE(I) = 2
```

```
30196 GOTO 30203
30198 IF BPSI(I) > P(J)  THEN  VALVE(I) = 0
30200 GOTO 30203
30202 IF BPSI(I) < P(J)  THEN  VALVE(I) = 1
      ELSE IF BPSI(I) = P(J)  THEN  VALVE(I) = 0
30203 NEXT I
30250 WORD = ((VALVE(B(1)) + 4*VALVE(B(2))) XOR 255) AND 255
30260 OUT PORT,WORD
30270 GOTO 30009
30271 REM ***********************************************************
30272 REM *              3.4 SYSTEM DUMP AND EXIT
30273 REM *      see page P14 of the data dictionary
30274 REM * variables established: IDONE
30275 REM * variables changeed: BPSI( ), IDONE, VALVE( ), WORD
30276 REM * variables used: CALIBRAION( ), N, PORT, PORT( )
30277 REM * calling modules: none
30278 REM * module called: 4.2
30279 REM ***********************************************************
30280 FOR I = 1 TO N
30290 VALVE(I) = 2: NEXT I
30300 WORD = ((VALVE(1) + 4*VALVE(2)) XOR 255) AND 255
30330 OUT PORT,WORD
30340 FOR I = 1 TO N
30350 BPSI(I) = INP(PORT(I)) * CALIBRATION(I)
30360 IF BPSI(I) <= .2  THEN VALVE(I) = 0  ELSE VALVE(I) = 2
30370 NEXT I
30380 IDONE = 0
30390 FOR I = 1 TO N
30400 IF VALVE(I) = 2  THEN IDONE = 1
30410 NEXT I
30420 IF IDONE = 1  THEN GOTO 30300
30430 FOR I = 1 TO N
30440 PRINT "BLADDER";I;"PRESSURE = ";BPSI(I):NEXT I
30442 WORD = ((VALVE(1) + 4*VALVE(2)) XOR 255) AND 255
30446 OUT PORT,WORD
30450 GOSUB 20020
30460 RETURN
31000 FOR I = 1 TO NUMSTATES
31010 FOR II = 1 TO NUMDUMP(I)
31020 VALVE(KDUMP(I,II)) = 2: NEXT II
31030 WORD = 0
31040 FOR II = N TO 1 STEP -1
31050 WORD = WORD*4 : WORD = WORD + VALVE(II) :NEXT II
31060 WORD = 255 AND (WORD XOR 255)
31070 OUT PORT,WORD
31080 FOR II = 1 TO N
31090 BPSI(II) = INP(PORT(II)) * CALIBRATION(II)
31100 IF BPSI(II) > P(J) AND VALVE(II) <> 2   THEN  VALVE(II) = 0
31110 NEXT II
31120 IF BPSI(KBOC(I)) > RPSI(I)  THEN  GOTO 31030
31130 FOR II = 1 TO NUMDUMP(I)
31140 VALVE(KDUMP(I,II)) = 1: NEXT II
31150 NEXT I
31160 RETURN
40000 PORT = &H18: PORT(2) = &H19: PORT(1) = &H1A
40010 A$ = INKEY$
40020 IF A$ < "0" OR A$ > "9"  THEN GOTO 40070
40030 A = ASC(A$) - 48
40040 IF A = 9  THEN  A = 10
40050 A = 255 AND (A XOR 255)
40060 OUT PORT.A
40070 X = INP(PORT(1))
40080 Y = INP(PORT(2))
40100 PRINT "NO. 1 = ";X,,"NO. 2 = ";Y
40110 GOTO 40010
```

Appendix B

Additional Readings About G-Protection

The following list contains selected articles about methods of g-protection and devices currently in use. The articles are coded to indicate the topic(s) covered in each according to the key below.

1. Tilt-back Seats
2. M-1 and L-1 Maneuvers
3. Positive Pressure Breathing
4. Standard Anti-G Suit
5. Capstan Type G-Suit
6. Ready Pressure
7. Anti-G Valves

1 - Burton, R.R, Iampietro, P.F., and Leverett, S.D., Jr., "Physiological Effects of Seatback Angles Greater Than 45 Degrees (from the Vertical) Relative to G", Aviation, Space, and Environmental Medicine 46, 1975:887-97.

1,4 - Dorman, P.J., and Lawton, R.W., "Effect on G Tolerance of Partial Supination Combined with the Anti-G Suit", Aviation, Space, and Environmental Medicine 26, 1956:490-6.

3 - Balldin, U.I., and Wranne, U., "Hemodynamic Effect of Extreme Positive Pressure Breathing Using a Two-Pressure Flying Suit", Aviation, Space, and Environmental Medicine, 51, 1980:851-855.

3 - Shaffstall, R.M., and Burton, R.R, "Evaluation of Assisted Positive Pressure Breathing on +Gz Tolerance", Aviation, Space, and Environmental Medicine, 50. 1979:820-4.

3 - Shurbrooks, S.J., Jr., "Positive Pressure Breathing as a Protective Technique During +Gz Acceleration", Journal of Applied Physiology 35, 1973:294-8.

4 - Begin, R., Dougherty, R., Michaelson, E.D., and Sacker, M.A., "Effect of Sequential Anti-G Suit Inflation on Pulmonary Capillary Blood Flow in Man", Aviation, Space, and Environmental Medicine 47, 1976:937-41.

4 - Burton, R.R, and Krutz, Jr., "G-Tolerance and Protection with Anti-G Suit Concepts", Aviation, Space, and Environmental Medicine 46, 1975:409-412.

4 - Gray, S., III, Shaver, J.A., Kroetz, F.W., and Leonard, J.J., "Acute and Prolonged Effects of G Suit Inflation on Cardiovascular Dynamics", Aerospace Medicine 40, 1969:40-43.

4 - Krutz, R.W., Jr., and Burton, R.R, "The Effect of Uniform Lower Body Pressurization on +Gz Tolerance and Protection", Aerospace Medical Preprints, 1974:62-3.

4, 5, 6 - Burton, R.R, Parkhurst, M.J., and Leverett, S.D., Jr., "+Gz Protection Afforded by Standard and Preacceleration Inflations of the Bladder and Capstan Type G-Suits", Aerospace Medicine 44, 1973:488-94.

4, 6, 7 - Burton, R.R, Shafstall, R.M., and Jaggers, J.L., "Development, Test, and Evaluation of an Advanced Anti-G Valve for the F-15", Aviation, Space, and Environmental Medicine May 1980:504-509.

7 - Moog, Inc., Technical Proposal for Design, Development, Fabrication, and Testing of a Tactical Life Support System Servo- Controlled Rapid Response Anti-G Valve, Moog, Inc., Carleton Group, Jamison Road, East Aurora, New York 14052.

Appendix C

Bladder Inflation Experimental Set-Up

The bladder inflation set-up discussed in Chapter Two was set up as shown in Figure III-1.

List of Equipment

2 - MAC 56B-33-111c Solenoid Valves
1 - Endevco 8506-50 Miniature Pressure Transducers
2 - Statham PIO-100G-180 Pressure Transducer
1 - Norgren R11-200-NNLA 0 to 60 PSIG Pressure Gauge
1 - Matheson 22024-1 0 to 100 PSIG Pressure Gauge
5 - 200 PSI 1/2-inch ID Fabric Reinforced Thick-Walled
    Rubber Pneumatic Hose (lengths of 28,36,44,52,and 60 inches)
1 - Two-Way Toggle Switch
1 - Gould Brush 260 6-Channel Strip Chart Recorder
1 - Modified Large Regular Anti-G Garment, Cutaway Type CSU-12/P
1 - Compressed Air Tank
1 - Mannequin
3 - SRL Bridge D/C Op-Amps
Various Fittings, Clamps, Connectors, and Wire

Calibration

The transducers are calibrated using a Fluke 8600A Digital Multimeter. The transducers prove to be almost linear over the experimental pressure range of 0 to 30 PSIG. The calibration factors are as follows:

Statham Transducers.........0.120 Volts/PSI
Endevco Transducer..........0.217 Volts/PSI

The Matheson pressure gauge is calibrated with a Crosby CD16M Fluid Pressure Scale Dead Weight Tester. The Norgren pressure gauge is only used as a guide and does not need to be calibrated.

Appendix D

Theoretical and Experimental Inflation and Deflation Profile Data

Table D-1. Theoretical and Experimental Inflation Profile Data - Response to Step Input - Bladder One (Plotted in Figure V-4)

Experimental

seconds	PSI
0.18	0.23
0.30	0.46
0.38	0.69
0.51	0.92
0.55	1.15
0.62	1.38
0.70	1.61
0.77	1.84
0.84	2.07
0.90	2.30
0.96	2.53
1.02	2.76
1.08	3.00
1.13	3.23
1.17	3.46
1.22	3.69
1.28	3.92
1.32	4.15
1.36	4.38
1.41	4.61
1.46	4.84
1.51	5.07
1.56	5.30
1.60	5.53
1.65	5.76
1.69	5.99
1.73	6.22
1.78	6.45
1.84	6.68
1.88	6.91
1.93	7.14
1.99	7.37
2.04	7.60
2.09	7.83
2.16	8.06
2.22	8.29
2.30	8.53
2.39	8.76
2.49	8.99
2.60	9.22
2.76	9.45
3.12	9.68
4.60	9.79

Theoretical

seconds	PSI
0.05	0.13
0.10	0.45
0.15	0.19
0.20	1.45
0.25	2.04
0.30	2.65
0.35	3.25
0.40	3.85
0.45	4.41
0.50	4.94
0.50	5.44
0.60	5.90
0.65	6.32
0.70	6.71
0.75	7.06
0.80	7.37
0.85	7.65
0.90	7.91
0.95	8.13
1.00	8.33
1.20	8.93
1.40	9.30
1.70	9.58
2.20	9.78
3.50	9.79

Table D-2. Theoretical and Experimental Inflation Profile Data - Response to Step Input - Bladder Two (Plotted in Figure V-5)

Experimental		Theoretical	
seconds	PSI	seconds	PSI
0.18	0.31	0.05	0.05
0.38	0.62	0.10	0.20
0.49	0.93	0.15	0.42
0.60	1.24	0.20	0.42
0.73	1.55	0.25	1.02
0.84	1.86	0.30	1.37
0.94	2.18	0.35	1.74
1.04	2.49	0.40	2.12
1.13	2.80	0.45	2.51
1.21	3.11	0.50	2.90
1.30	3.42	0.55	3.29
1.37	3.73	0.60	3.67
1.46	4.04	0.65	4.05
1.54	4.35	0.70	4.41
1.62	4.66	0.75	4.75
1.69	4.97	0.80	5.09
1.77	5.28	0.85	5.40
1.85	5.59	0.90	5.71
1.98	5.91	0.95	6.00
2.03	6.22	1.00	6.26
2.11	6.53	1.05	6.51
2.20	6.84	1.10	6.76
2.30	7.15	1.15	6.98
2.41	7.46	1.20	7.19
2.52	7.77	1.25	7.39
2.64	8.08	1.30	7.58
2.77	8.39	1.35	7.75
2.93	8.70	1.40	7.91
3.14	9.01	1.45	8.06
3.36	9.32	1.50	8.19
3.84	9.63	1.65	8.55
6.24	9.79	1.80	8.83
		2.00	9.12
		2.50	9.52
		3.00	9.68
		4.00	9.77
		4.75	9.79

Table D-3. Theoretical and Experimental Deflation Profile Data - Response to Step Input - Bladder One (Plotted in Figure V-6)

Experimental seconds	Experimental PSI	Theoretical seconds	Theoretical PSI
0.5600	0.00	0.600	0.04
0.3600	0.23	0.500	0.10
0.3080	0.46	0.440	0.17
0.2800	0.69	0.400	0.24
0.2480	0.92	0.340	0.42
0.2360	1.15	0.300	0.61
0.2120	1.38	0.250	0.97
0.2000	1.16	0.200	1.54
0.1840	1.84	0.190	1.69
0.1680	2.07	0.180	1.85
0.1600	2.30	0.170	2.03
0.1380	2.53	0.160	2.23
0.1400	2.76	0.150	2.44
0.1280	3.00	0.140	2.68
0.1200	3.23	0.130	2.94
0.1160	3.46	0.120	3.22
0.1100	3.69	0.110	3.34
0.1000	3.92	0.100	3.88
0.0900	4.15	0.088	4.33
0.0840	4.38	0.080	4.67
0.0800	4.61	0.068	5.22
0.0760	4.84	0.060	5.62
0.0680	5.07	0.048	6.28
0.0600	5.30	0.040	6.76
0.0480	5.53	0.032	7.28
0.0460	5.76	0.024	7.84
0.0420	5.99	0.020	8.14
0.0400	6.22	0.015	8.52
0.0360	6.45	0.010	8.92
0.0320	6.68	0.005	9.35
0.0280	6.91	0.001	9.70
0.0200	7.14		
0.0160	7.37		
0.0080	7.60		
0.0072	7.83		
0.0064	8.06		
0.0056	8.29		
0.0048	8.53		
0.0040	8.76		
0.0032	8.99		
0.0024	9.22		
0.0016	9.45		
0.0008	9.68		
0.0000	9.79		

Table D-4. Theoretical and Experimental Deflation Profile Data - Response to Step Input - Bladder Two (Plotted in Figure V-7)

Experimental

seconds	PSI
2.2080	0.31
1.2080	0.62
0.8680	0.93
0.7080	1.24
0.6080	1.55
0.5360	1.86
0.4880	2.18
0.4480	2.49
0.4080	2.80
0.3700	3.11
0.3360	3.42
0.3200	3.73
0.2880	4.04
0.2660	4.35
0.2460	4.66
0.2200	4.97
0.2060	5.28
0.1860	5.59
0.1680	5.91
0.1520	6.22
0.1408	6.53
0.1260	6.84
0.1120	7.15
0.0960	7.46
0.0860	7.77
0.0720	8.08
0.0560	8.39
0.0480	8.70
0.0360	9.01
0.0200	9.32
0.0120	9.63
0.0000	9.79

Theoretical

seconds	PSI
2.00	0.02
1.00	0.43
0.90	0.59
0.70	1.10
0.50	2.05
0.30	3.83
0.29	3.96
0.28	4.08
0.27	4.21
0.26	4.34
0.25	4.82
0.24	4.62
0.23	4.77
0.22	4.92
0.21	5.08
0.20	5.24
0.19	5.41
0.18	5.58
0.17	5.76
0.16	5.94
0.15	6.13
0.14	6.32
0.13	6.52
0.12	6.73
0.11	6.94
0.10	7.16
0.09	7.39
0.08	7.62
0.07	7.87
0.06	8.12
0.05	8.37
0.04	8.64
0.03	8.91
0.02	9.20
0.01	9.59
0.00	9.79

Appendix E

USER'S GUIDE

for

PSC

a

PROGRAMMABLE SOFTWARE CONTROLLER

for a

MULTIPLE BLADDER, SEQUENTIALLY INFLATABLE G-SUIT

Developed by

Lt Jerry L. Marcu

In Partial Fulfillment of the Masters Degree Requirement

at the

Air Force Institute of Technology

Wright-Patterson Air Force Base

Ohio

1983

This user's guide is an aid to operating the PSC, Programmable Software Controller, on the Z-100 Microcomputer with PSC.COM stored on drive A. To run the PSC, follow the instructions listed here. They assume the following:

1. The disk drives are empty,
2. The power is off, and
3. The Z-100 and printer are both plugged into the power bar behind the computer.

Running the PSC

Step 1. Push the power switch on the power bar to the on position. This should turn on the Z-100, the CRT, and the printer.

Step 2. The Z-100 will prompt you with a hand pointing with its index finger. Type "B(CR)", and wait.

Step 3. When you receive the "A" prompt, type "PSC(CR)", and wait.

Step 4. The PSC will begin running. Just follow the instructions on the CRT.

Powering Down

When you are finished running the PSC, you will have an "A" prompt on the CRT. If you are through using the PSC, make sure the disk drives are empty, and push the power switch to the OFF position. If you wish to run the PSC again, return to Step 3.

Directoring the Disk

To verify the presence of PSC on the disk, at the "A" prompt, type"DIR(CR)". You will see a listing of all the files on the disk. Verify that "PSC.COM" is there. Then return to Step 3.

Appendix F

DATA DICTIONARY

for

PSC

a

PROGRAMMABLE SOFTWARE CONTROLLER FOR A MULTIPLE BLADDER,

SEQUENTIALLY INFLATABLE G-SUIT

Developed by

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In Partial Fulfillment of the Masters Degree Requirement

at the

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DATA DICTIONARY - ABBREVIATIONS

I - INTEGER VARIABLE

FP - FLOATING POINT VARIABLE

nAm - n DIMENSIONAL ARRAY OF SIZE m

STR - STRING VARIABLE

BOC - BLADDER OF CONCERN

DDP - DESIRED DUMP PRESSURE

PROCESS ENTRIES

PROCESS ENTRY

name: USER INPUT MODULE
module number: 1.0
revision date: 15 SEP 83
line numbers: 0 to 840

purpose: Sequentially call the user input submodules
Provide a printout of the PSC parameters

calling modules: 2.0 DECISION MODULE

modules called: 1.1 NUMBER AND SEQUENCE OF BLADDERS
1.2 THRESHOLD PERCENTAGE
1.3 PSI/G PROFILE
1.4 REFRESH CYCLE
4.1 RESPONSE
4.2 CONTINUE
4.3 CLEARSCREEN
4.4 SLOW CLEARSCREEN

variables established: B( ), BLADDER( ), BPSI( ), CALIBRATION( ), G( ), GLAST, IPARALLEL( ), KBOC( ), KDUMP(,), NUMDUMP( ), P( ), PORT, PORT( ), RPSI( ), THRESHOLD(,), TURNON( ), USER$, VALVE( ), WORD, Z$

variables changed: PORT(1), PORT(2), USER$, Z$

variables used: L, N, NUMGEES

PROCESS ENTRY

name: NUMBER AND SEQUENCE OF BLADDERS
module number: 1.1
revision date: 15 SEP 83
line numbers: 2000 to 2820
purpose: Accept the number of bladders from the keyboard
Accept the sequence of inflation from the keyboard
Permit revision of any parameters originally established in this module.
calling modules: 1.0 USER INPUT MODULE
2.0 DECISION MODULE

modules called: 4.1 RESPONSE
4.2 CONTINUE
4.3 CLEARSCREEN

variables established: N, L

variables changed: B( ), BLADDER( ), CALIBRATION( ), N, L, Z$

variables used:n/a

PROCESS ENTRY

name: THRESHOLD PERCENTAGE
module number: 1.2
revision date: 15 SEP 83
line numbers: 3000 to 3380
purpose: Accept values between 0 and 1 and assign them as turn-on points for each bladder. The turn-on point of a bladder is the point in its inflation when it tells the sequentially next bladder to begin inflating.
Provides a printout of the threshold values.

calling modules: 1.0 USER INPUT MODULE
2.0 DECISION MODULE

modules called: 4.1 RESPONSE
4.2 CONTINUE
4.3 CLEARSCREEN

variables established: none

variables changed: IPARALLEL( ), TURNON( ), Z$

variables used: BLADDER( ), L, N, USER$

PROCESS ENTRY

name: PSI/G PROFILE
module number: 1.3
revision date: 15 SEP 83
line numbers: 4000 to 4450

purpose: Accepts the desired G to bladder pressure relationship and provides a set of discrete G and PSI pairs for converting the sensed G value to a desired bladder pressure.
Accepts minimum and maximum allowable bladder pressures.
Provides a printout of the PSI/G data.
Allows revision of the PSI/G data.

calling modules: 1.0 USER INPUT MODULE
2.0 DECISION MODULE

modules called: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.2 DISCRETE VALUE RELATIONSHIP
1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP
4.1 RESPONSE
4.3 CLEARSCREEN

variables established: PSIMAX, PSIMIN

variables changed: PSIMAX, PSIMIN, THRESHOLD(,), Z$

variables used: G( ), NUMGEES, P( ), THRESHOLD(,), TURNON( ), USER$

PROCESS ENTRY

name: SINGLE POINT LINEAR RELATIONSHIP
module number: 1.3.1
revision date: 15 SEP 83
line numbers: 4500 to 4730

purpose: Accepts a PSI/G slope and a PSI and G pair on the desired line and generates the desired PSI/G profile limited by PSIMAX and PSIMIN.

calling modules: 1.3 PSI/G PROFILE

modules called: 4.1 RESPONSE
4.2 CONTINUE
4.3 CLEARSCREEN

variables established: GLEVEL, GSTEP, NUMGEES, PRESSURE, SLOPE, YINTERCEPT

variables changed: G( ), P( ), Z$, all those established

variables used: PSIMAX, PSIMIN, USER$

PROCESS ENTRY

name: DISCRETE VALUE RELATIONSHIP
module number: 1.3.2
revision date: 15 SEP 83
line numbers: 4800 to 4890

purpose: Accepts user input of G and corresponding PSI pairs.
Allows the user to develop a "non-linear" step function.

calling modules: 1.3 PSI/G PROFILE

modules called: 4.3 CLEARSCREEN

variables established: NUMGEES

variables changed: G( ), NUMGEES, P( )

variables used: PSIMAX, PSIMIN

PROCESS ENTRY

name: BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP
module number: 1.3.3
revision date: 15 SEP 83
line numbers: 4900 to 4960

purpose: Accepts desired minimum PSI and corresponding pair, G stepsize, and PSI stepsize.
Generates discrete G and PSI pairs by incrementing G and PSI by their stepsizes until PSIMAX is reached.

calling modules: 1.3 PSI/G PROFILE

modules called: none

variables established: GSTEP, NUMGEES, PSTEP

variables changed: G( ), GSTEP, NUMGEES, P( ), PSTEP

variables used: PSIMAX, PSIMIN

PROCESS ENTRY

name: REFRESH CYCLE
module number: 1.4
revision date: 15 SEP 83
line numbers: 7000 to 7430

purpose: Accept the necessary state parameters to operate the refresh cycle.

calling modules: 1.0 USER INPUT MODULE
2.0 DECISION MODULE

modules called: 4.1 RESPONSE
4.3 CLEARSCREEN

variables established: NUMSTATES

variables changed: KBOC( ), KDUMP(,), NUMDUMP( ), NUMSTATES, RPSI( )

variables used: USER$

PROCESS ENTRY

name: DECISION MODULE
module number: 2.0
revision date: 15 SEP 83
line numbers: 20120 to 20275

purpose: Allow the user to choose the next operation: run the suit, revise the parameters, or exit to Z/CPM. If revision is selected, a menu is displayed to the user of the available options.

calling modules: none

modules called: 1.1 NUMBER AND SEQUENCE OF BLADDERS (at line 2100 or line 2390)
1.2 THRESHOLD PERCENTAGE (at line 3000 or line 3210)
1.3 PSI/G PROFILE (at line 4000 or line 4090)
1.4 REFRESH CYCLE (at line 7000 or line 7180)
3.0 G-SUIT CONTROLLER MODULE
4.3 CLEARSCREEN
5.0 REINITIALIZATION

variables established: none

variables changed: Z$

variables used:none

PROCESS ENTRY

name: G-SUIT CONTROLLER MODULE
module number: 3.0
revision date: 15 SEP 83
line numbers: 30000 to 30460

purpose: Control the G-suit according to the programmed parameters. This is a "virtual" module. It is comprised of Modules 3.1, 3.2, and 3.4. They are not actually separate modules in the code because they are not called by other modules. They do have separate functions so they are described separately in this document.

calling modules: 2.0 DECISION MODULE

modules called: n/a

variables established: n/a

variables changed: n/a

variables used: n/a

PROCESS ENTRY

name: G-INPUT
module number: 3.1
revision date: 15 SEP 83
line numbers: 30000 to 30040

purpose: Sample the keyboard and determine the current G based on the following information:

keyed:	represents:
1 to 9	1 to 9 G
0	10 G
R	refresh cycle
spacebar	dump and exit
any other key	G is unchanged
no key	G is unchanged

calling modules: none - part of Module 3.0

modules called: 3.3 REFRESHER
4.3 CLEARSCREEN

variables established: GSAMPLE, GSTRING$, IHIGH, LOW, MIDPOINT

variables changed: all those established

variables used: NUMGEES

PROCESS ENTRY

name: CONTROLLER
module number: 3.2
revision date: 15 SEP 83
line numbers: 30080 to 30270

purpose: Determines the GLEVEL, checks the bladder pressures and turns the fill and dump valves on or off as necessary. CONTROLLER accomplishes sequential inflation by only inflating a bladder if its pressure is too low and the sequentially previous bladder has reached the threshold pressure.

calling modules: none - part of Module 3.0

modules called: none

variables established: none

variables changed: BPSI( ), GLAST, VALVE( ), WORD

variables used: B( ), CALIBRATION( ), G( ), IHIGH, LOW, MIDPOINT, N, P, PORT, PORT( ), THRESHOLD(,)

PROCESS ENTRY

name: REFRESHER
module number: 3.3
revision date: 15 SEP 83
line numbers: 31000 to 31160

purpose: Accomplish the refresh cycle programmed in Module 1.4. REFRESHER monitors the BOC until it achieves the DDP for each state, then returns to normal control.

calling modules: 3.1 G-INPUT

modules called: none

variables established: none

variables changed: BPSI( ), VALVE( ), WORD

variables used: CALIBRATION( ), KBOC( ), KDUMP(,), N, NUMDUMP( ), NUMSTATES, PORT, PORT( ), RPSI( )

PROCESS ENTRY

name: SYSTEM DUMP AND EXIT
module number: 3.4
revision date: 15 SEP 83
line numbers: 30280 to 30460

purpose: Before relinquishing control to the decision module, DUMP AND EXIT deflates all the bladders to less than 0.2 PSI, then exits to the Decision Module, 2.0.

calling modules: none - part of Module 3.0

modules called: 4.2 CONTINUE

variables established: IDONE

variables changed: BPSI( ), IDONE, VALVE( ), WORD

variables used: CALIBRATION( ), N, PORT, PORT( )

PROCESS ENTRY

name: MISCELLANIA
module number: 4.0
revision date: 15 SEP 83
line numbers: 20000 to 20110

purpose: This is a "virtual" module that encompasses Modules 4.1, 4.2, 4.3, and 4.4. They are miscellaneous functions called by other modules, not by this one.

calling modules: n/a

modules called: n/a

variables established: n/a

variables changed: n/a

variables used: n/a

PROCESS ENTRY

name: RESPONSE
module number: 4.1
revision date: 15 SEP 83
line numbers: 20000 to 20010

purpose: Accept a keyboard input and set it equal to Z$
If Z$ is an "X" or an "x", go to the Decision Module, 2.0.

calling modules: 1.0 USER INPUT MODULE
1.1 NUMBER AND SEQUENCE OF BLADDERS
1.2 THRESHOLD PERCENTAGE
1.3 PSI/G PROFILE
1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.4 REFRESH CYCLE

modules called: none

variables established: none

variables changed: Z$

variables used: none

PROCESS ENTRY

name: CONTINUE
module number: 4.2
revision date: 15 SEP 83
line numbers: 20020 to 20040

purpose: Wait for the user to hit the RETurn key, the return to the calling module.

calling modules: 1.1 NUMBER AND SEQUENCE OF BLADDERS
1.2 THRESHOLD PERCENTAGE
1.3.1 SINGLE POINT LINEAR RELATIONSHIP
3.4 SYSTEM DUMP AND EXIT

modules called: none

variables established: none

variables changed: Z$

variables used: none

PROCESS ENTRY

name: CLEARSCREEN
module number: 4.3
revision date: 15 SEP 83
line numbers: 20050 to 20056

purpose: Clear the CRT by printing 25 blank lines.

calling modules: 1.1 NUMBER AND SEQUENCE OF BLADDERS
1.2 THRESHHOLD PERCENTAGE
1.3 PSI/G PROFILE
1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.2 DISCRETE VALUE RELATIONSHIP
1.4 REFRESH CYCLE
2.0 DECISION MODULE
3.1 G-INPUT

modules called: none

variables established: none

variables changed: none

variables used: none

PROCESS ENTRY

name: SLOW CLEARSCREEN
module number: 4.4
revision date: 15 SEP 83
line numbers: 20060 to 20110

purpose: Move text slowly up and off the CRT by printing 5 blank spaces per line for 25 lines.

calling modules: 1.0 USER INPUT MODULE

modules called: none

variables established: none

variables changed: none

variables used: none

PROCESS ENTRY

name: REINITIALIZATION
module number: 5.0
revision date: 15 SEP 83
line numbers: 20280 to 20430

purpose: Set all arrays to zero so that a new G-suit configuration may be entered.

calling modules: 2.0 DECISION MODULE

modules called: 1.0 USER INPUT MODULE (enters at line 240)

variables established: none

variables changed: B( ), BLADDER( ), BPSI( ), CALIBRATION( ), G( ), IPARALLEL( ), KBOC( ), KDUMP(,), NUMDUMP( ), P( ), RPSI( ), THRESHOLD(,), TURNON( ), VALVE( )

variables used: none

DATA FLOW ENTRIES

DATA FLOW ENTRY

name: B( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: B(J) = I means that the Jth bladder sequentially is in position I.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.1 NUMBER AND SEQUENCE OF BLADDERS
5.0 REINITIALIZATION

used in modules: 3.2 CONTROLLER

DATA FLOW ENTRY

name: BLADDER( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: BLADDER(I) = J means that the Ith bladder sequentially is the bladder in location J.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.1 NUMBER AND SEQUENCE OF BLADDERS
5.0 REINITIALIZATION

used in modules: 1.2 THRESHOLD PERCENTAGE

DATA FLOW ENTRY

name: BPSI( )
revision date: 15 SEP 83
description symbol: FP, 1A24
description: BPSI(I) is the bladder pressure in the sequentially Ith bladder.

source module: 1.0 USER INPUT MODULE

changed in modules: 3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT
5.0 REINITIALIZATION

used in modules: n/a

DATA FLOW ENTRY

name: CALIBRATION( )
revision date: 15 SEP 83
description symbol: FP, 1A24
description: CALIBRATION( ) is the adjustment factor for the transducer in the bladder in position I.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.1 NUMBER AND SEQUENCE OF BLADDERS
5.0 REINITIALIZATION

used in modules: 3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT

DATA FLOW ENTRY

name: G( )
revision date: 15 SEP 83
description symbol: FP, 1A51
description: G(J) is the G value at level J

source module: 1.0 USER INPUT MODULE

changed in modules: 1.3 PSI/G PROFILE
1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.2 DISCRETE VALUE RELATIONSHIP
1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP
5.0 REINITIALIZATION

used in modules: 3.2 CONTROLLER

DATA FLOW ENTRY

name: GLAST
revision date: 15 SEP 83
description symbol: FP
description: Holds the G value of the previous sample.

source module: 1.0 USER INPUT MODULE

changed in modules: 3.2 CONTROLLER

changed in modules: n/a

DATA FLOW ENTRY

name: GLEVEL
revision date: 15 SEP 83
description symbol: FP
description: GLEVEL is a G value that lies on the desired PSI/G profile.

source module: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP

changed in modules: 1.3.1

used in modules: 1.3.1

DATA FLOW ENTRY

name: GSAMPLE
revision date: 15 SEP 83
description symbol: FP
description: Holds current G value

source module: 3.1 G-INPUT

changed in modules: 3.1

used in modules: 3.2 CONTROLLER

DATA FLOW ENTRY

name: GSTEP
revision date: 15 SEP 83
description symbol: FP
description: Holds the magnitude of the G window for which there is a single desired bladder pressure.

source module: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP

changed in modules: 1.3.1, 1.3.3

used in modules: 1.3.1, 1.3.3

DATA FLOW ENTRY

name: GSTRING$
revision date: 15 SEP 83
description symbol: STR
description: Holds a value input from the keyboard.

source module: 3.1 G-INPUT

changed in modules: 3.1

used in modules: 3.1

DATA FLOW ENTRY

name: IDONE
revision date: 15 SEP 83
description symbol: I
description: When IDONE = 0, all the bladders have deflated to 0.2 PSI
or less. When IDONE = 1, not all have deflated.

source module: 3.4 SYSTEM DUMP AND EXIT

changed in modules: 3.4

used in modules: 3.4

DATA FLOW ENTRY

name: IHIGH
revision date: 15 SEP 83
description symbol: I
description: Holds the G( ) subscript, or level, that is higher than
the level nearest the sampled G.

source module: 3.1 G-INPUT

changed in modules: 3.2 CONTROLLER

used in modules: 3.2

DATA FLOW ENTRY

name: IPARALLEL( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: IPARALLEL(I) = J means that Bladder J inflates parallel to Bladder I. I and J are sequential positions.

source module: 1.2 THRESHOLD PERCENTAGES

changed in modules:1.2

used in modules: 3.2 CONTROLLER

DATA FLOW ENTRY

name: KBOC( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: KBOC(I) = J means that the BOC for state I is in location J.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.4 REFRESH CYCLE
5.0 REINITIALIZATION

used in modules: 3.3 REFRESHER

DATA FLOW ENTRY

name: KDUMP(,)
revision date: 15 SEP 83
description symbol: I, 2A24,24
description: KDUMP(I,J) = K means that the Jth bladder that deflated to the DDP for state I of the refresh cycle is the bladder in position K.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.4 REFRESH CYCLE
5.0 REINITIALIZATION

used in modules: 3.3 REFRESHER

DATA FLOW ENTRY

name: L
revision date: 15 SEP 83
description symbol: I
description: Holds the number of bladders in the G-suit.

source module: 1.1 NUMBER AND SEQUENCE OF BLADDERS

changed in modules: 1.1

used in modules: 1.0 USER INPUT MODULE
1.2 THRESHOLD PERCENTAGES

DATA FLOW ENTRY

name: LOW
revision date: 15 SEP 83
description symbol: I
description: Holds the G( ) subscript, or level, that is nearest the sampled G.

source module: 3.1 G-INPUT

changed in modules: 3.2 CONTROLLER

used in modules: 3.2

DATA FLOW ENTRY

name: MIDPOINT
revision date: 15 SEP 83
description symbol: I
description: Holds the G( ) subscript, or level, that is halfway between IHIGH and LOW.

source module: 3.1 G-INPUT

changed in modules: 3.2 CONTROLLER

used in modules: 3.2

DATA FLOW ENTRY

name: N
revision date: 15 SEP 83
description symbol: I
description: Holds the total number of bladders in the G-suit.

source module: 1.1 NUMBER AND SEQUENCE OF BLADDERS

changed in modules: 1.1

used in modules: 1.0 USER INPUT MODULE
1.2 THRESHOLD PERCENTAGES
1.3 PSI/G PROFILE
3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT

DATA FLOW ENTRY

name: NUMDUMP( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: NUMDUMP(I) = J means that a total of J bladders deflate
during state I of the refresh cycle.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.4 REFRESH CYCLE
5.0 REINITIALIZATION

used in modules: 3.3 REFRESHER

DATA FLOW ENTRY

name: NUMGEES
revision date: 15 SEP 83
description symbol: I
description: Holds the total number of G( ) subscripts, or levels, in the PSI/G relationship.

source module: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.2 DISCRETE VALUE RELATIONSHIP
1.3.3 BEGINNING POINT AND STEPSIZE RELATIONSHIP

changed in modules: 1.3.1, 1.3.2, 1.3.3

used in modules: 1.0 USER INPUT MODULE
1.3 PSI/G PROFILE
3.1 G-INPUT

DATA FLOW ENTRY

name: NUMSTATES
revision date: 15 SEP 83
description symbol: I
description: Holds the total number of states in the refresh cycle.

source module: 1.4 REFRESH CYCLE

changed in modules: 1.4

used in modules: 3.3 REFRESHER

DATA FLOW ENTRY

name: P( )
revision date: 15 SEP 83
description symbol: FP, 1A24
description: P(J) is the desired pressure at level J.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.2 DISCRETE VALUE RELATIONSHIP
1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP
5.0 REINITIALIZATION

used in modules: 1.0 USER INPUT MODULE
1.3 PSI/G PROFILE

DATA FLOW ENTRY

name: PORT
revision date: 15 SEP 83
description symbol: I
description: Holds the digital port address.

source module: 1.0 USER INPUT MODULE
changed in modules: n/a.

used in modules: 3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT

DATA FLOW ENTRY

name: PORT( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: PORT(I) is the port address of the transducer input from
the bladder in location I

source module: 1.0 USER.INPUT MODULE

changed in modules: n/a

used in modules: 3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT

DATA FLOW ENTRY

name: PRESSURE
revision date: 15 SEP 83
description symbol: FP
description: Holds a sample PSI value used to calculate the PSI/G relationship.

source module: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP

changed in modules: n/a

used in modules: n/a

DATA FLOW ENTRY

name: PSIMAX
PSIMIN
revision date: 15 SEP 83
description symbol: FP
description: Minimum and maximum allowable bladder pressure.
(must be within 0 and 10 PSI respectively)

source module: 1.3 PSI/G PROFILE

changed in modules: 1.3

used in modules: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.3.2 DISCRETE VALUE RELATIONSHIP
1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP

DATA FLOW ENTRY

name: PSTEP
revision date: 15 SEP 83
description symbol: FP
description: Holds the pressure increment used to determine the PSI/G relationship.

source module: 1.3.3 BEGINNING POINT AND STEPSIZE LINEAR RELATIONSHIP

changed in modules: 1.3.3

used in modules: 1.3.3

DATA FLOW ENTRY

name: RPSI( )
revision date: 15 SEP 83
description symbol: FP, 1A24
description: RPSI(I) is the DDP for state I of the refresh cycle.

source module: 1.4 REFRESH CYCLE

changed in modules: 1.4

used in modules: 3.3 REFRESHER

DATA FLOW ENTRY

name: SLOPE
revision date: 15 SEP 83
description symbol: FP
description: SLOPE is the rate of change of the PSI/G profile.

source module: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP

changed in modules: 1.3.1

used in modules: 1.3.1

DATA FLOW ENTRY

name: THRESHOLD(,)
revision date: 15 SEP 83
description symbol: FP, 2A24,51
description: THRESHOLD(I,J) = X means that the turnon pressure of
Bladder I at level J is X.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.3 PSI/G PROFILE
5.0 REINITIALIZATION

used in modules: 3.2 CONTROLLER

DATA FLOW ENTRY

name: TURNON( )
revision date: 15 SEP 83
description symbol: FP, 1A24
description: TURNON(I) is the percentage of Bladder I's desired pressure at which Bladder I+1 is to begin inflation.

source module: 1.0 USER.INPUT MODULE

changed in modules: 1.2 THRESHOLD PERCENTAGE
5.0 REINITIALIZATION

used in modules: 1.3 PSI/G PROFILE

DATA FLOW ENTRY

name: USER$
revision date: 15 SEP 83
description symbol: STR
description: Holds the character string that is the concatenation of the letters entered as the user's name.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.0

used in modules: 1.2 THRESHOLD PERCENTAGES
1.3 PSI/G PROFILE
1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.4 REFRESH CYCLE

DATA FLOW ENTRY

name: VALVE( )
revision date: 15 SEP 83
description symbol: I, 1A24
description: VALVE(I) is the status of the valve pair for sequential
bladder I.

VALVE(I) = 0 means OFF
= 1 means FILL
= 2 means DUMP

source module: 1.0 USER INPUT MODULE

changed in modules: 3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT
5.0 REINITIALIZATION

used in modules: 3.2, 3.3, 3.4

DATA FLOW ENTRY

name: WORD
revision date: 15 SEP 83
description symbol: I
description: Holds the 8-bit coded instruction for adjusting the valves for the two-bladder suit.
Only bits 0-3 are used, 4-7 are zeroes.

BIT	VALVE
0	fill 1
1	dump 1
2	fill 2
3	dump 2

source module: 1.0 USER INPUT MODULE

changed in modules: 3.2 CONTROLLER
3.3 REFRESHER
3.4 SYSTEM DUMP AND EXIT

used in modules: 3.2, 3.3, 3.4

DATA FLOW ENTRY

name: YINTERCEPT
revision date: 15 SEP 83
description symbol: FP
description: YINTERCEPT is calculated from the SLOPE and sample G and PSI pair for the PSI/G profile.

source module: 1.3.1 SINGLE POINT LINEAR RELATIONSHIP

changed in modules: 1.3.1

used in modules: 1.3.1

DATA FLOW ENTRY

name: Z$
revision date: 15 SEP 83
description symbol: STR
description: Holds the reply entered at the keyboard.

source module: 1.0 USER INPUT MODULE

changed in modules: 1.1 NUMBER AND SEQUENCE OF BLADDERS
1.2 THRESHOLD PERCENTAGES
1.3 PSI/G PROFILE
1.3.1 SINGLE POINT LINEAR RELATIONSHIP
1.4 REFRESH CYCLE
2.0 DECISION MODULE
4.1 RESPONSE
4.2 CONTINUE

used in modules: same as changed in modules

Vita

Jerry Lynn Marcu was born in Warren, Ohio on 02 February 1955. He graduated from Cardinal High School in Middlefield, Ohio in 1973 and attended Ohio Northern University in Ada, Ohio from which he received the degree of Bachelor of Science of Mechanical Engineering in 1977. Upon graduation he accepted employment with Owens-Illinois, Inc. in Maimi, Florida as a Plant Industrial Engineer in the Forest Products Division. In 1979 he accepted a position as Design Engineer with the Flight Deck Group of the Boeing Commercial Airplane Company in Seattle, Washington. In 1981 he complete OTS and accepted a commission in the United States Air Force and entered the Air Force Institute of Technology in 1982.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sequential Inflation
G-Suit
Programmable Controller
+Gz protection
G-tolerance
Acceleration
Acceleration Physiology
Military Aircraft

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A bang-bang type, closed loop, digital, programmable controller was developed for a multiple bladder, sequentially inflatable g- suit. Programmable parameters included the number of bladders, sequence of inflation, PSI/G relationship, and a g-suit refresh cycle. The software was developed in BASIC-80. Two bladders were analyzed and their transfer functions approximated (assuming linearity) for both inflation and deflation. A theoretical versus actual time response comparison revealed the degree of linearity of bladder inflation and deflation.

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